THE UNIVERSITY OF ALBERTA

# THE PROBLEM OF SAMPLING COARSE FLUVIAL GRAVELS

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Problem of Sampling Coarse Fluvial Gravels", submitted by Roderick Alan McGinn in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The volumetric or bulk sample is the most accepted method of sampling sediment. However, when sampling coarse fluvial gravels, this method is often very time consuming and inconvenient. Within the past twenty years many alternate methods of sampling coarse fluvial gravels have been developed.

This study attempts to statistically compare the results of several alternate methods. Each method of sampling was systematically applied to a grain size population. Paired non-parametric statistical tests compared the resulting cumulative distributions and graphic parameters. The results indicate that many of the tested sampling methods produce significantly different grain size distributions.

Conversion factors derived from a theoretical model (Kellerhals and Bray 1971a) were also applied to the results and the same non-parametric tests compared the adjusted distributions. It appears that some conversion factors are capable of producing comparable mean and median values.

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CHAPTER 1

Introduction.

In the past decade researchers have been employing refined statistical techniques to compare and evaluate the physical significance of sediment grain size data. However, only recently have researchers been concerned with refining measurement procedure and the equivalance of various sampling methods for coarse fluvial gravels. The problem of equivalance has been approached both theoretically and empirically. When non-equivalance exists between sampling methods, the additional problem of conversion of data from one method to another has arisen.

The Purpose.

The objective of this study is to test theoretical concepts by a comparative evaluation of various sampling procedures for coarse fluvial gravels. The theoretical concepts are designed to facilitate the conversion of data obtained by one method of measurement to that derived by a second method.

Sampling Procedures.

In 1971, Kellerhals and Bray presented a comprehensive review of sampling procedures for coarse river gravels. They subdivide the sampling procedure into five parts; site selection, data collection, linear dimension, frequency, and presentation of results.

Although the procedures outlined by Kellerhals

and Bray (1971a) are reviewed in part, the reader is referred to the original paper for further references and a more thorough discussion.

Site Selection.

Kellerhals and Bray (1971 a) point out that site selection may be either statistical - random or stratified, or subjective - personal selection. They also suggest that engineering hydrologists and geomorphologists often prefer to use a combination of the two, usually personally selecting the locale (Leopold, 1970) or general area to be sampled and then statistically choosing the exact locations.

Collection of a Sample.

Data for grain size analysis of sediment may be collected by several methods and analyzed in various ways (Kellerhals and Bray 1971a).

i The Volumetric Sample

This is the standard method used to collect a sediment sample. Generally, a specific volume of material is removed from the site and sieved. Variations of this sampling technique include:

a) Surface Volumetric Sample - material is removed from a fixed area to the depth of the diameter of the largest particle.

b) Subsurface Volumetric Sample - material is removed from a fixed area, lying under the surface volumetric sample, to a predetermined depth.

Researchers working with coarse riverbed gravels often find volumetric sampling impossible due to the large volume of sample required, equipment problems and the amount of time involved. As a result, other sampling methods have been developed.

ii Grid Sampling

The grid sample, first described by Wolman (1954), may be collected in several ways.

a) A tape is laid along the surface to be sampled and those stones falling on a certain interval of the tape (i.e. one foot) are selected. Usually, fifty or one hundred stones are chosen.

b) When sampling underwater, pacing may be used to define the sampling interval. The stone lying beneath the toe of the boot is sampled (Wolman 1954).

c) A fixed grid of fifty or one hundred intersections is placed on the site and the stone lying under an intersection point is selected.

Note: If a stone lies under two intersection points it must be counted twice (Kellerhals and Bray 1971a).

iii The Quadrant Sample

The quadrant or areal method of sampling was first introduced by Lane and Carlson (1953). They removed and sieved all the stones lying on the surface of a fixed area of sediment. This method is different from the Surface

Volumetric Sample in that it is only one grain thick.

iv The Transect Sample

A fourth sampling method was described by Muir in 1969. Muir suggests that a transect be made by stretching a tape or string over the site. Each stone falling under the transect is selected for the sample.

v Photographic Sampling

Recently, photographs have been used in the sampling of coarse sediment. Two methods appear appropriate; a variation of the grid method outlined by Thornes and Hewitt (1967), and the quadrant method, discussed by Pashinsky (1964), and Ritter and Helley (1968). Both methods involve taking a vertical photograph of the site. Then the apparent size of individual stones, either those lying under the grid or those from the total area, are measured on the photograph. When multiplied by the correct conversion factor, the true measurements are derived.

Linear Dimension.

Once a sample is obtained, each particle is assigned a specific grain size. Kellerhals and Bray (1971a) indicate that there is a choice in the methods used for measurement of the grain size:

a) When sieving, the linear dimension is determined by the sieve opening.

b) When axis measurements are employed, a caliper or rule is used to determine the length of an axis.

c) Finally, the diameter of a sphere of a volume equal to that of the stone may be computed - nominal diameter, (Krumbein and Pettijohn, 1938).

Furthermore, Krumbein and Pettijohn (1938) have illustrated that sieve measurements, b axis measurements, and nominal diameter may be taken to be similar.

Frequency.

Kellerhals and Bray (1971a) state that after a sample has been mechanically analyzed, it may be divided into several size classes. The frequency in each class is expressed as a percentage of the total sample. This percentage may represent a fraction of the total weight of the sample - frequency by weight, or a fraction of the total number in the sample - frequency by number.

Presentation of Results.

Several methods of data presentation have been developed. In 1938, Krumbein and Pettijohn replaced the standard histogram and frequency curve graph with the cumulative percentage graph. They also introduced the $\phi$ value ( $\phi = -\log_2 D$, where D is the particle diameter in millimeters).

Bagnold (1941) proposed another graphic method of describing particle size distributions using logarithms to

the base ten. Both methods are in current use.

Inman (1952) developed graphic moment measures, (median, mean, standard deviation, skewness and kurtosis) for Krumbein and Pettijohn's cumulative percentage curve.

Folk and Ward (1957) and later Folk (1965) refined the work of Inman to the standard used today.

Previous Studies.

Within the field of geology, researchers began to acknowledge the problem of comparing grain size distribution data obtained from two different sampling methods; namely, sieving and point counting (grid by number). Rosenfeld, Jacobsen and Fern (1953) attempted a theoretical comparison of the two methods. They listed several factors contributing to difference in the results of the two methods and suggested an empirical approach to the problem.

Friedman (1962) discovered an empirical relationship between the two methods when moment measurements were considered. He used an earlier developed conversion factor (1958) to produce a 1/1 relationship between mean grain size values of a volumetric and point counting sampling method.

At the same time, Van der Plas (1962) pointed out that different methods of analysis of the distribution of quartz grains in a selected sample resulted in significantly different results. He used histograms to visually compare differences in the point counting method, the volumetric method and a version of the transect method. Since the same

number of grains were used the area under the curves could be statistically compared. Van der Plas concluded that the three different methods produced significantly different results.

Sahu (1964) points out that Friedman's conversions are only appropriate for the first two moment measures (mean and standard deviation). He stresses the importance of the use of skewness and kurtosis for "efficient discrimination" of depositional mechanisms and environments. Sahu's data conversion from the point counting method to the volumetric method is as follows:

a) the particle be measured by nominal sectional diameter.

b) convert frequency by number to frequency by weight

$$W = 4/3 \ \pi r^3 \bar{p}$$

where r is the nominal radius and $\bar{p}$ is the density.

c) transform nominal diameter to hydraulic value with the use of tables - hydraulic value is the diameter of a quartz sphere having the same settling velocity of a given particle in water (Krumbein 1938).

Sahu proposes that this conversion gives a 1/1 relationship between the two methods of analysis.

In 1965 the Friedman - Van der Plas debate was made public through a series of articles (<u>Sedimentology</u> 4, 1965). Both authors referred to the hazards of relating theoretical and empirical studies. However, whether weighing factors could convert frequency by number data to frequency by weight data remained unresolved.

Kellerhals (1967) was one of the first hydraulic engineers to recognize the problem of non-equivalance of sampling methods for coarse fluvial gravels. He compared the grain size distributions of the area by weight sample to the distribution resulting from a grid by number sample and found a 80 - 90% similarity in the upper (D 80) grain size range.

Neill (1968) briefly examined the differences in grain size distributions obtained by a volumetric sample and a Wolman grid sample. Neill concluded that serious error could be introduced by directly relating data obtained from different sampling methods without modification.

In 1969 Muir examined four methods of sampling fluvial gravels; volumetric, grid, quadrant, and transect. Using the volumetric sample as a standard, he evaluated and compared the grain size distributions resulting from these sampling methods. Muir concluded that the grid sample produced the closest results to that of the volumetric sample.

In a more rigorous study, Leopold (1970) attempted to discover simple conversion factors which could interrelate frequency by weight and frequency by number. Leopold's conversion from a grid by number sample to an area by weight sample is as follows:

a) convert frequency by number to frequency by weight by multiplying the number of stones in each class size by

$D^3$ (Leopold (1970), Figure 1).

b) adjust for the preference to select larger stones by multiplying the number in each size class by $1/D^2$.

Note that D represents the geometric mean diameter of the size class.

Kellerhals and Bray (1971b) point out the unnecessary complication of this conversion ( conversion = $D^3 \times 1/D^2$ ) and suggest that weighting the original number of stones in each size class of the grid by number sample by the value D, gives identical results.

They further postulate that an equivalent grain size distribution to that of a surface volumetric sample may be derived by weighting the number in each size class of the area by weight sample by 1/D. This factor adjusts for the uneven depth of the area sample. Kellerhals and Bray (1971b) therefore conclude that the grain size distributions of a volumetric sample and a grid by number sample are virtually equivalent - grid by number x $D^3 \times 1/D^2$ = area by weight x 1/D = volumetric.

In an earlier paper (1971a), Kellerhals and Bray undertook a very thorough study resulting in many of the conversion factors tested in this study. The Kellerhals and Bray conversion factors will be discussed in Chapter II.

# CHAPTER II

## Introduction.

This work involves three interrelated studies. The theoretical concept of converting frequency by number data to frequency by weight data is examined and tested using a model of hypothetical closely packed cubes of three proportional sizes (Kellerhals and Bray 1971a). This model also produces transformation coefficients. These coefficients are tested in the laboratory using approximately proportional spheres. Finally, the conversion factors (Kellerhals and Bray 1971a) are examined under natural conditions.

## Theoretical Considerations.

Kellerhals and Bray (1971a) point out that one of the most important criteria for selecting a sampling procedure is that "the grain size distributions arrived at should be comparable with data on which most accepted theories on sediment transport and fluvial hydraulics are based." A large amount of the research involving fluvial processes is concerned with the material less than 8 mm. in diameter. The volumetric sampling procedure and sieve analysis is the most common and therefore preferred method of examining this data. For this reason, it is preferable to equate the results of all other sampling procedures to those of a standard volumetric sampling method.

Kellerhals and Bray (1971a ) also discuss whether a surface sample is in reality a random cut through a

volumetric sample. The example of riverbed pavements serves to illustrate that this is not always the case in gravel bedded streams. Riverbed pavements frequently occur in streams transporting gravel size particles. Such streams facilitate the removal of the sand, silt and clay fractions from the bed and produce a riverbed armour of gravels. This armoured pavement may act as a shield, protecting finer sediment in the subsurface. Thus, when this type of site is sampled using the volumetric method, it is common to find the coarse material concentrated at the surface and the finer material in the subsurface. Therefore, different methods of sampling may actually be sampling different populations.

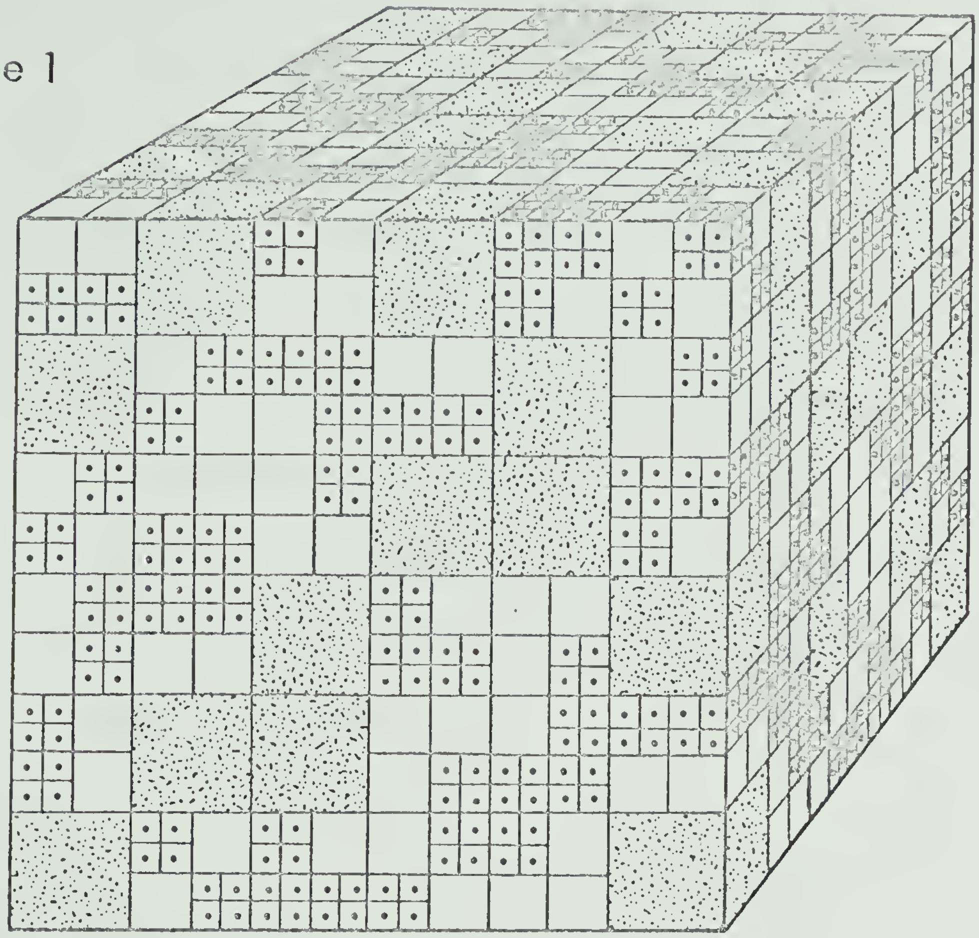
It follows that there are two reasons for the varying results of different sampling procedures:

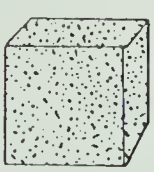
1. differences in the sampling procedure - the method by which the sample was collected and analyzed.
2. differences in the populations sampled - whether only a surface population was sampled or whether a subsurface population is included in the sample.

Theory.

Kellerhals and Bray (1971a) assume an infinite volume of randomly distributed but closely packed cubes (Figure 1). This effectively removes the problem of sampling different populations. They also assume a grain size distribution which will result in a sieve analysis histogram

Figure 1



| Particle | Linear Size D | Weight W | Total No. in Sample Volume | Total No. in Sample Surface |
| --- | --- | --- | --- | --- |
|  | 1 | 1 | 4610 | 192 |
|  | 2 | 8 | 576 | 48 |
|  | 4 | 64 | 72 | 12 |

SAMPLE OF DENSELY PACKED CUBES OF THREE SIZES.

Kellerhals and Bray 1971

as illustrated in Figure 2a. The results of other sampling procedures may then be compared with this model. The histogram results of the analysis are shown in Figure 2. It is important to note that in this model a grid by number sample is assumed to be taken from a random cut through the volumetric sample. A similar grain size distributions is produced by the grid by number and volumetric sampling method, (Figures 2a and 2b). The use of this model also produces grain size distributions of grid by weight, area by weight, area by number, and volumetric samples which differ significantly (Figures 2a, 2c, 2d, and 2e).

With this model, it is possible to derive conversion factors for all possible combinations of measurement procedures. Table 1 lists these factors.

When using the above model it is important to note that a random distribution is assumed. As pointed out previously (page 11) this is seldom the case. Therefore, the conversion factors derived from this model account for only variations in grain size distributions due to the differences in sampling methodology and not population differences. The researcher must decide whether a surface population or a volumetric population is relevant to his study and then apply the appropriate sampling procedure.

The Laboratory Study.

The Kellerhals and Bray model was tested by mixing four sizes of glass beads - 25.4, 15.8, 6.0, and 3.0 millimeters (supplied by the Research Council of Alberta) - in a shallow 2.5 inch by 8 inch by 14 inch box with a

Figure 2

Kellerhals and Bray 1971 a

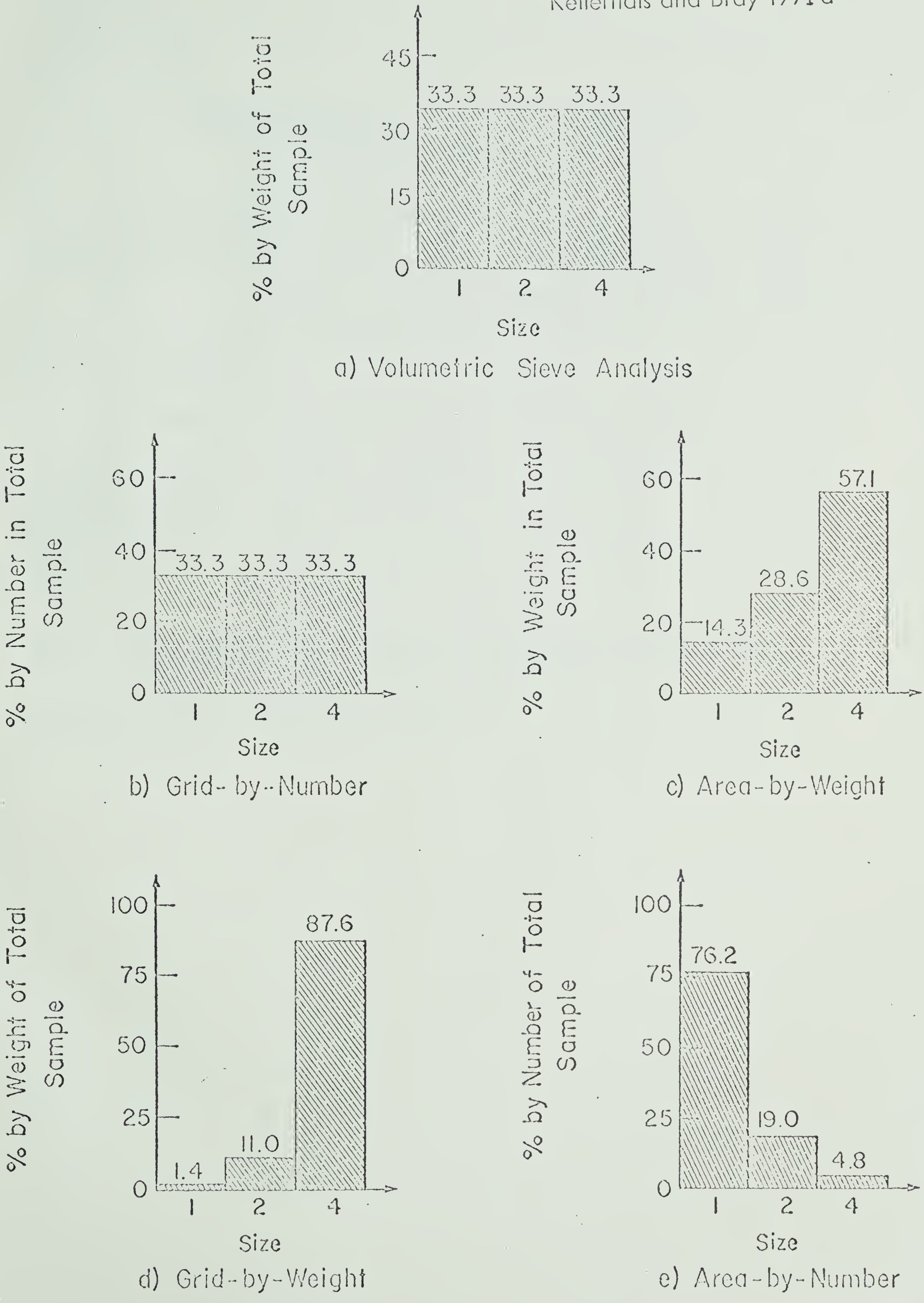


TABLE 1

Weighting Factors for the Conversion

of Sampling Procedures

| Conversion to / from | Sieve by Weight | Grid by Number | Grid by Weight | Area by Number | Area by Weight |
|---|---|---|---|---|---|
| Sieve by Weight | 1 | 1 | $D^3$ | $1/D^2$ | D |
| Grid by Number | 1 | 1 | $D^3$ | $1/D^2$ | D |
| Grid by Weight | $1/D^3$ | $1/D^3$ | 1 | $1/D^5$ | $1/D^2$ |
| Area by Number | $D^2$ | $D^2$ | $D^5$ | 1 | $D^3$ |
| Area by Weight | $1/D$ | $1/D$ | $D^2$ | $1/D^3$ | 1 |

Note: D is the geometric mean of the size range to be adjusted by the weighting factor.

From Kellerhals and Bray, 1971a.

tight fitting lid. The resulting volumetric sample totalled 10,000 grams, containing 2,500 grams of each bead size. Although a random distribution in the sample was desired, problems involving the shape and large variation in size of the beads may have prevented this. Plate 1 illustrates the laboratory set-up.

Once the material was thoroughly mixed by shaking the box in three dimensions, the lid was removed and a vertical photograph taken (Plate 2).

A grid superimposed on the photo, enabled the selection of points for a grid by number sample. A grid by weight sample was obtained by the multiplication of the frequency by number of each bead size by the corresponding bead weight. Using a similar procedure, the photograph was used to obtain an area by number and an area by weight sample. Ten composite samples were taken and the results of this experiment are presented in the following chapter.

Plate 1

The Laboratory equipment.

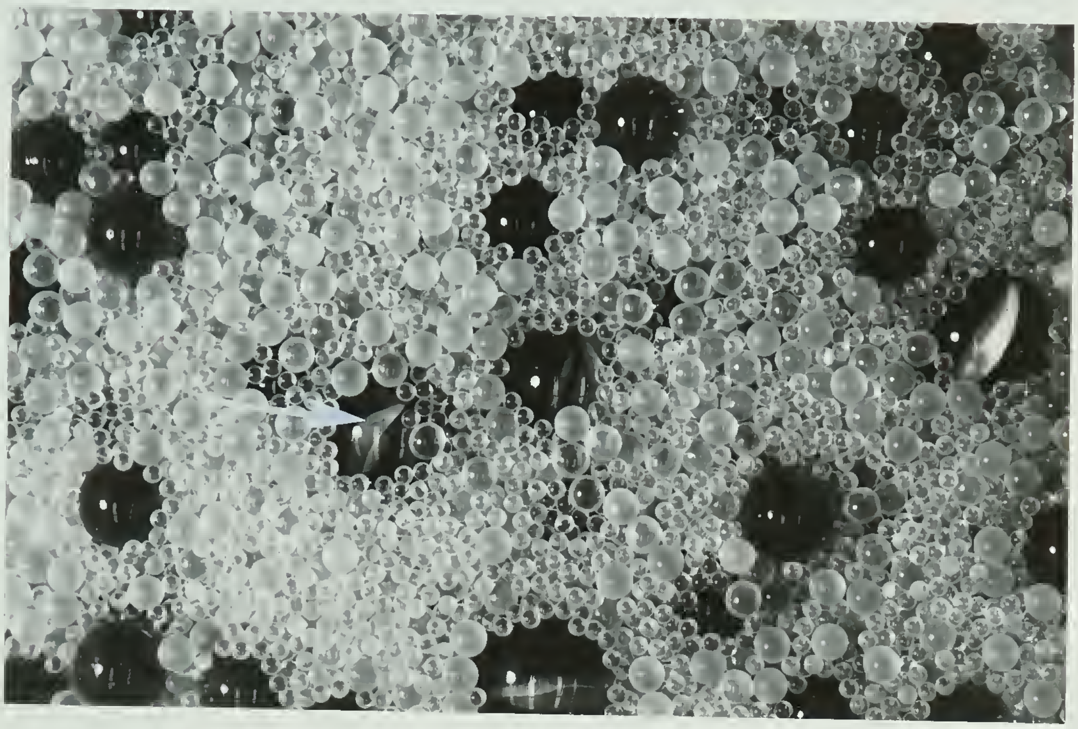


Plate 2

The laboratory sample.

Note the partially buried 25.4 mm. bead.

## The Field Study.

### Site Selection.

Since the study techniques are most suitable for coarse samples, those sites selected were composed of coarse material from recently exposed river bars (Plate 3).

The river locale, (Leopold 1970) or general sampling area was subjectively chosen in order to avoid sharp variations within the samples. The exact location of each site was then randomly selected within these areas.

### Methods and Nomenclature.

For the purpose of comparing specific sampling procedures, a method was used which provided for the retention of the original material while allowing analysis by the different procedures. Therefore, in many of the test samples identical populations were employed. As a result, any differences in grain size distributions in these samples may be directly related to differences in the sampling procedure.

Thirty sampling sites were chosen. Ten sampling procedures were employed and seven of these were comparatively evaluated.

G - a grid by weight sample.

Q - an area or quadrant by weight sample.

A - an area by number sample where b axis describes the grain size.

Plate 3

Recently exposed river bar.

Note paving occuring on the stream bed.

Sc - the coarse (greater than 8 mm.) portion of a volumetric sample.

Sf - the fine (less than 8 mm.) portion of a volumetric sample.

V - a volumetric sample, the combination of Sc and Sf, 30" x 30" x 8" - 10".

N1 - a grid by number sample where the b axis describes the grain size (Wolman 1954).

N2 - a grid by number sample where the mean a-b axis describes the grain size.

N3 - a grid by number sample where the triaxial mean describes the grain size (Muir 1969).

P1 - a grid by number sample taken from a photograph where the apparent b axis describes the grain size (Thornes and Hewitt 1967).

P2 - a grid by number sample taken from a photograph where the mean a-b axis describes the grain size.

Note: When frequency by weight was used, the linear dimension was the square sieve hole size. All other axis measurements were made with calipers.

The Sampling Method.

1. Place a grid on the surface of the site (Plate 4).
2. Take a vertical photograph with a Polaroid camera. Samples P1 and P2 are derived from this photograph.
3. Using the photo as a reference, remove 50 stones lying under the intersection points. Only stones greater than

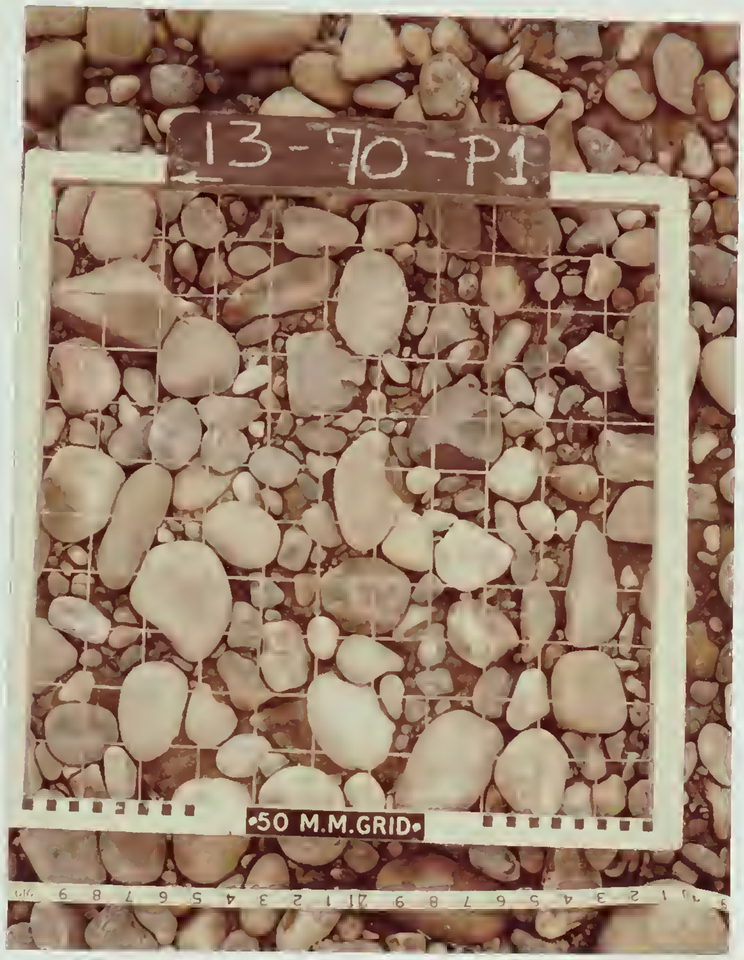



Plate 4

The Grid Sampling Method.

Stones lying under intersection points are selected. Note: In this case a 50 mm. grid is used. When a stone lies under two intersection points, the stone is counted twice (Kellerhals and Bray 1970a).

8 mm. in diameter are chosen.

4. Maintain the selective order of the stones by numbering.
5. Measure the a, b, and c axes of each stone. This step provides data for the N samples - N1, N2, and N3, (Plate 5).
6. Sieve N samples through coarse sieves. Sieve sizes used were 4", 2", 1", 3/4", 1/2", and 3/8". This results in the G sample.
7. Remove the remainder of the surface layer and sieve. This plus G comprises the Q sample (Plate 6).
8. Remove a predetermined volume of the subsurface, (30" x 30" x 4"), and sieve. This plus Q results in the Sc sample.
9. The remaining fines are collected and sieved in the laboratory. This is the Sf sample.
10. Add together Sc and Sf to make the V sample.

Thus, this procedure allows the same stones to be used for the P samples, the N samples, a G sample and a Q sample. Only the Sc, Sf, and V sample require a subsurface population.

Data presentation.

The results of the above described sampling procedure were plotted as a series of cumulative frequency curves on arithmetic paper (Folk 1965, P. 41). This involved the conversion of British measurements to metric and finally to Ø values. This enables the use of Folk

Plate 5

Measurement of the axes in a Grid Sample.

Plate 6

The Quadrant Sample.

The surface layer is sampled.

graphic statistics (Folk 1965) which are used in the statistical comparison of paired sampling procedures described in the next chapter.

CHAPTER III

Introduction.

The major objective of this study is the comparative evaluation of various procedures for sampling coarse fluvial gravels. Both the actual grain size distributions and the converted distributions were examined and compared using a paired non-parametric test - the Kolmogorov-Smirnov Two Sample Test. In geomorphology and hydrology, it is often more convenient to describe a grain size distribution in terms of moment measures (Folk 1965) rather than total grain size distribution. For this reason, five sediment size parameters (median, mean, standard deviation, skewness, and kurtosis) were subjected to a paired non-parametric test - the Wilcoxon Matched Pairs Signed Ranks Test.

One of the major advantages of using non-parametric statistics is that the distribution subjected to the test need not be normal. Therefore, there is no need to assume normal distributions when applying these test.

The Kolmogorov-Smirnov Two Sample Test (K-S Test).

The Kolmogorov-Smirnov Two Sample Test was used to compare the total grain size distributions of the sampling procedures. The test has been suggested by King (1966) as a "relatively simple....method of testing whether two samples could belong to the same population". Potter and Pettijohn (1963) also refer to the similar use of this test in the geological sciences. Siegel (1956) points out that the K-S Test is concerned with the agreement between the two "grain

size" distributions. If the samples are drawn from the same population, then, the cumulative distributions are expected to be relatively close. If this is not the case, one must conclude that either they are not drawn from the same population or they have undergone different treatments (Siegel 1956). Since in this study, the populations are similar for many of the sampling procedures, one must assume the methodology accounts for the significant differences. The test involves a comparision of the percentage of the total sample (by weight or by number ) finer than each size class of Sample $X_1$ and Sample $X_2$ . The maximum difference is then recorded and compared to the critical value obtained from the K-S table. If the recorded value is less than the critical value, equivalence is confirmed at the selected probability level. A summary of the procedure for a Kolmogorov-Smirnov Two Sample Test may be found in Siegel 1956 (p 135).

The Wilcoxon Matched Pairs Signed Ranks Test (Wilcoxon Test).

The Wilcoxon Matched Pairs Signed Ranks Test can be employed to test whether two treatments are different by relating samples containing matching pairs (Siegel 1956). This test compares the parametric values of each grain size distribution (median, mean, standard deviation, skewness and kurtosis). The Wilcoxon Test utilizes not only the direction of the difference in values, as in the Sign Test, but also the magnitude of the difference. The differences

are then ranked without regard to sign. Then the positive ranking numbers are totaled. Likewise the negative rankings are totaled. The smaller total is then evaluated using a Wilcoxon Table and significance assessed for the selected probability level. The test is therefore stronger than a Sign Test in that greater differences are not given equal value to smaller differences. The test was also used to compare the actual axis measurements of a stone with those equated axis measurements derived from a photograph. A summary of the procedure for a Wilcoxon Matched Pairs Signed Ranks Test appears in Siegel 1956 (p 83).

Lab Results.

After the collection of the laboratory samples, the K-S Test was used to establish whether the grain size distribution of any one sampling procedure was equivalent to the grain size distribution of any other procedure. Table 2 illustrates the results of the K-S Test for all possible combinations of sampling procedures.

According to the Kellerhals and Bray theory, it was expected that all combinations tested would prove significantly different with the exception of the comparision between the volumetric sampling method (V) and the grid by number method(N). In actual fact (Table 2), this similarity did not occur. Furthermore, in eight of the ten quadrant samples (Q), no significant difference was found between the grain size distributions and those related V distributions

TABLE 2

The results of the Kolmogorov-Smirnov Two Sample Test of the different sampling procedures. Critical value .05.

| Compared to | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | %SS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | G | | | | | | | | | | | 0 |
| N | A | X | | | | | | | | | | 10 |
| N | Q | | | | | | | | | | | 0 |
| N | V | | | | | | | | | | | 0 |
| G | A | | | | | | | | | | | 0 |
| G | Q | | | | | | | | | | | 0 |
| G | V | | | | | | | | | | | 0 |
| A | Q | | | | | | | | | | | 0 |
| A | V | | | | | | | | | | | 0 |
| Q | V | | X | X | | X | X | X | X | X | X | 80 |

TABLE 3

The results of the Kolmogorov-Smirnov Two Sample Test of converted sampling procedures. Critical value at .05.

| Converted from - to | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | %SS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | G | X | X | X | X | X | X | X | X | X | X | 100 |
| N | A | X | X | X | X | X | X | X | X | X | X | 100 |
| N | Q | | | | | | X | X | X | | | 30 |
| G | A | X | X | X | X | X | X | X | X | X | X | 100 |
| G | Q | | | | | | | X | | | | 10 |
| G | V | | | | | | | | | | | 0 |
| A | Q | X | X | X | X | X | X | X | X | X | X | 100 |
| A | V | | | | X | | | | | | | 10 |
| Q | V | | | | | | | | | | | 0 |

Note: X indicates that differences between the pairs are not significant at the chosen probability level.

%SS - Percentage of samples significantly similar at the .05 probability level.

(Table 2). The above apparent anomalies must be examined according to the model astablished by Kellerhals and Bray (1971 a).

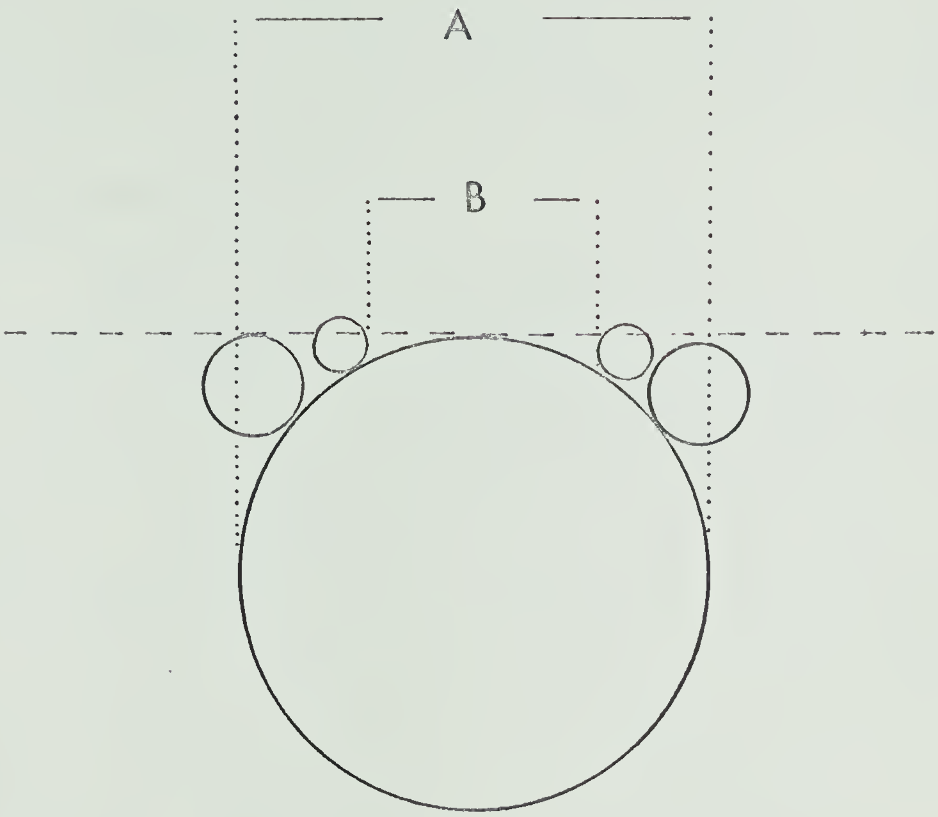
Kellerhals and Bray (1971a) assume a random distribution of closely packed cubes (Figure 1). As stated previously with reference to the lab samples, problems of particle size ratios and shape may have prevented the desired random distribution.

Photo 2 may assist in defining the problem. The arrow (Photo 2) indicates a partially buried 25.4 mm. bead. The spherical shape and relatively large size of the bead allows the smaller (3.0 mm. and 6.0 mm.) beads to encroach upon the potential visible surface area of the larger bead (Figure 3). In the Kellerhals and Bray model (Figure 1), encroachment cannot occur as the total surface area of the large cube cannot be partially buried by the smaller cubes. Therefore, the "buried bead" effect may greatly alter the results of the laboratory surface sampling procedures.

When sampling by a grid method, the occurrence of the "buried beads" has a twofold effect: a) the probability of a grid intersection falling on a large bead is reduced by a factor related to the "amount of burying", b) the probability of a grid intersection falling on a smaller beads is increased by the same factor.

The "buried bead" effect is also relevant when a quadrant sample is taken. Since all beads visible at the

Buried Bead Effect.




A represents true diameter

B represents visual diameter

Figure 3

surface are counted, there is no chance of omitting a large bead. However, there will be an increase in the expected number of small beads found on the surface. This increase is again related to the "amount of burying" factor. A discussion of the amount of burying factor may be found in the suggestions (p 23).

Table 3 presents the results of a Kolmogorov-Smirnov Two Sample Test on data subjected to a conversion factor (Table 1) and compared to the appropriate sampling procedure. Possibly due to the "buried bead" effect, five conversion factors fail to support the Kellerhals and Bray model. In two of the cases where the conversion factors succeed, it is important to note that the "buried bead" effect is not significant in the conversion.

The results of the grid by number sampling procedure (N) compare favourably to those of the grid by weight procedure (G). In this case, the "buried bead" effect is negated by the fact that both samples are identical and only the method of analysis differs. A similar situation arises in the conversion from the area by number sample (A) to the area by weight sample (Q).

Successful conversions from N to A and from G to A also occur. However, when converting to a volumetric sample or an area by weight sample, apparently the previous mentioned "buried bead" effect assumes significant proportions. This partial burial effect seldom occurs in a natural riverbed as most of the smaller particles are removed by the current.

More often it is the small particles which are under-represented in a surface sample from an armoured riverbed. Therefore, field samples are not affected by this unique laboratory occurrence - partial burial.

Suggestions.

It appears that the major problem encountered in the laboratory study is the so termed "buried bead" effect. Three suggested ways of reducing this effect to less significant proportions are described below:

i The Modified Surface Sample.

Since the samples are derived from a photograph (Photo 2), it would be possible to draw in the potential surface areas of the larger beads thereby eliminating those smaller beads obscuring the larger beads. This would create a modified sample similar to the one postulated by the Kellerhals and Bray model.

ii The Smaller Size Ratio Sample.

It is believed that if beads of smaller size ratios are used in the sample (i.e. 2,3,4,5,6, mm.) the partial burying of the larger beads would be less significant.

iii A Computation of the "Amount of Burying Factor".

The calculation of this factor may be assisted by the use of a model. The major assumption of this model is that - all particles are tangent to both the surface and to one another. From Figure 4 it is shown that:

$$\alpha + \beta = 90^\circ$$

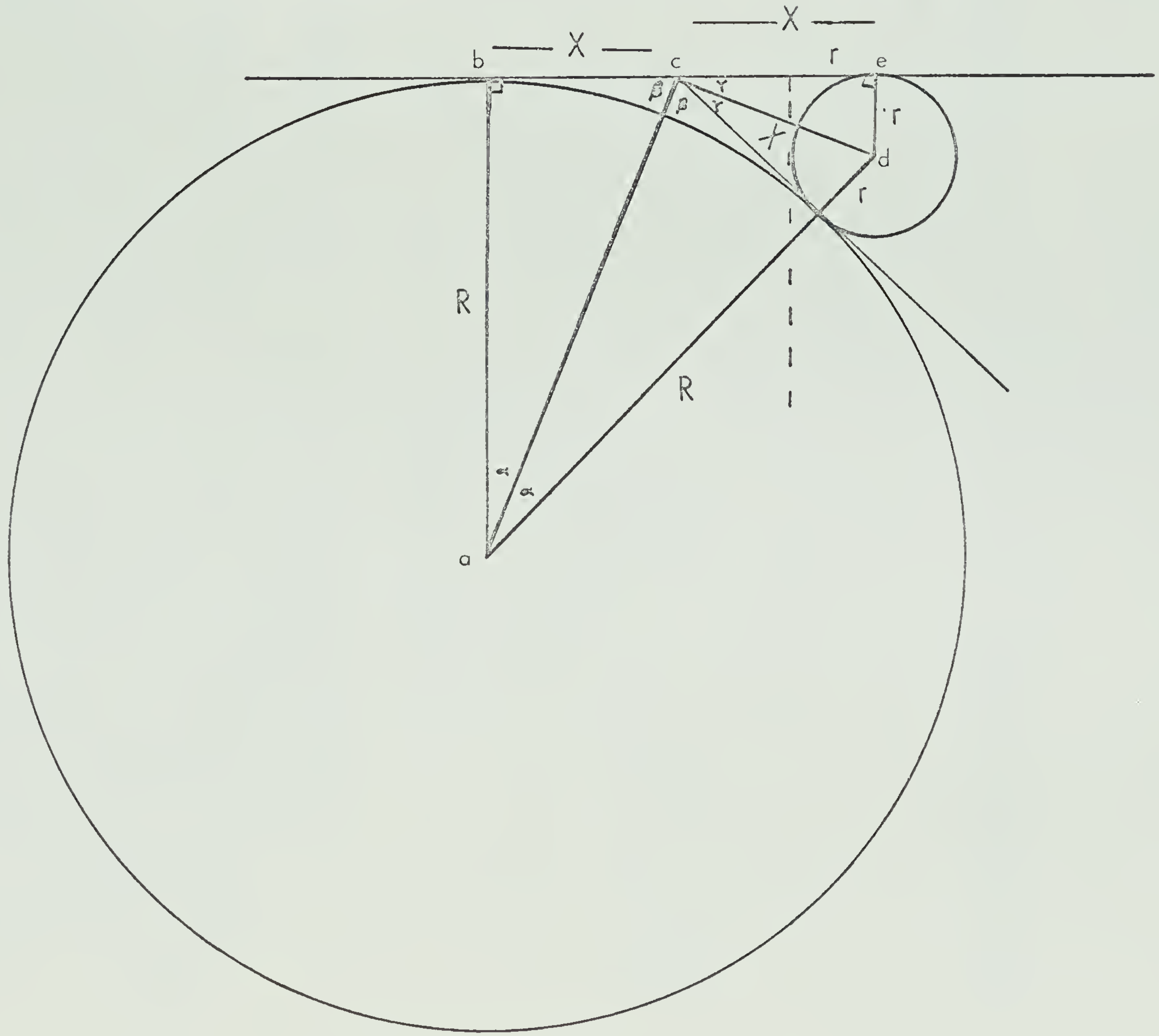
$$2\beta + \gamma\, 2 = 180^\circ$$

$$\therefore \quad \beta + \gamma = 90^\circ$$

$$\therefore \quad \text{it follows that } \alpha = \gamma$$

Figure 4

Amount of Burying Factor



Since $\alpha = \gamma$ and angle abc = angle ced = $90^\circ$

triangle abc is similar to triangle ced

$$\therefore \quad \frac{X}{R} = \frac{r}{X}$$

multiplying by XR

$$X^2 = rR$$

$$X = \sqrt{rR}$$

From the previous calculations the total exposed surface area of the large bead (E) is:

$$E = \pi(2\sqrt{rR} - r)^2$$

$$\therefore \text{ the area of burial } = \pi R^2 - E$$

substituting for E

$$\text{Area of burial} = \pi\left(R^2 - (2\sqrt{rR} - r)^2\right)$$

$\therefore$ the amount of burying factor

$$= \frac{\pi\left(R^2 - (2\sqrt{rR} - r)^2\right)}{\pi R^2}$$

$$= \frac{R^2 - (2\sqrt{rR} - r)^2}{R^2}$$

where R is the radius of the bead buried
r is the radius of the burying bead

From this formula, the "amount of burying" factors may be calculated for specific size ratios of beads (Appendix IIIa). Appendix IIIb represents a graphical presentation of the "amount of burying" factors for any given ratio r/R, where r is the burying bead and R is the buried bead. From Appendix IIIb the "amount of burying" factors for all combinations of beads used in the laboratory experiment may be derived. It appears that the most significant amount of burial takes place on the two larger size beads (25.4 mm.

and 15.8 mm. diameter - Appendix IIIc).

The Field Study.

As in the lab study, the K-S test was applied to the grain size distributions of the various combinations of field sampling procedures. Table 4 gives the results.

As expected, very few sampling procedures produce significantly similar distributions; the major exceptions being the N and P samples, which show a significant similarity between four of these sampling procedures.

In all 30 test samples, N1 distributions compare favourably with N3 grain size distributions. The difference between the two sampling procedures is that; in N1 Samples, the b axis is used to describe the grain size, while in N3 Samples, the grain size is described by the triaxial mean. This would indicate that the b axis and the triaxial mean of a stone are, for all practical purposes, the same.

The second combination producing similar grain size distribution curves is that of the N1 Sample and the P1 Sample. In 28 of the 30 test samples (94%), the grain size distributions are significantly similar. This would tend to support the hypothesis that; axis measurements derived from a photograph can be equated to (and hence substituted for) axis measurements taken in the field (Thornes and Hewitt 1967). The third significantly similar combination (N3 and P1) also supports this theory.

TABLE 4

The results of the Kolmogorov-Smirnov Two Sample Test of the different field sampling procedures.

Critical value at .05.

| Pairs Compared | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | %SS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G Q | | X | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | 6.7 |
| G Sc | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0.0 |
| Q Sc | | | | X | X | | | | | X | | | X | X | | | | | | X | X | X | X | | | | | | | | 30.0 |
| N1 N2 | X | X | X | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | 96.7 |
| N1 N3 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | 100.0 |
| N1 P1 | X | X | X | | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | 93.3 |
| N1 P2 | | X | | | X | | X | | X | X | | | | | | | | | X | | | | X | | X | X | | X | X | | 36.7 |
| N2 N3 | X | X | X | X | X | X | X | X | | | X | X | X | | X | X | X | X | | | X | | X | X | X | | X | X | X | X | 73.7 |
| N2 P1 | X | X | X | | X | | X | X | X | X | | X | X | | | X | | | X | X | X | | X | X | X | X | X | X | X | | 70.0 |
| N2 P2 | | | | | | | | | | | | | | | | | | | | | | | | | X | | | X | | | 6.7 |
| N3 P1 | X | X | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | 96.7 |
| N3 P2 | | X | | | X | | X | X | X | | | | | | | | | | X | | | | X | | X | X | | X | X | | 36.7 |
| P1 P2 | | X | X | X | X | X | X | X | | X | X | | | X | X | | X | | X | X | | X | X | X | X | X | X | X | X | X | 73.7 |
| G N1 | | | | X | | | | | | X | | | | | | | | | | | | | | | | | | | | | 6.7 |
| G P1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0.0 |
| Q N1 | X | | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | | | | X | | | X | 73.7 |
| Sc P1 | X | X | X | X | X | X | X | X | | | | | X | X | | | | | | X | X | X | X | X | X | X | X | X | X | | 66.7 |
| Sc N1 | X | X | X | | | | | | | | | | X | | | | | | | X | X | X | X | X | X | X | | X | X | | 43.3 |
| Q N1 | X | | | X | X | | X | | X | X | X | X | X | X | | X | X | | X | X | X | X | X | | | X | X | | | | 63.3 |

%SS - Percentage of the test samples which are significantly similar at .05.
X - Indicates that differences between the pairs are not significant at the chosen probability level.

The difference between the N1 and N2 grain size distributions is not significant; yet, in the case of N3 and N2 grain size distributions, a significant difference does occur. It follows that, since the N2 Sample is slightly coarser than N1 and significantly coarser than N3, the N1 Sample must be slightly coarser than N3.

Further information may be obtained from the results of the Wilcoxon Test. Of the four previous mentioned combinations, only the N1 and the N3 grain size distributions are so similar that all five statistical parameters are significantly close (Table 5). Where the K-S Test indicated a significant comparison between the N1 and N2 grain size distributions, the Wilcoxon Test revealed that the mean and the median values were significantly larger in the N2 Samples.

The Wilcoxon Test also raises doubts as to the validity of the photographic sampling procedure. This test illustrates that the similarity between the grain size distribution and the N distribution is concentrated around the median and mean values. The mean and median of the N3 and the P1 grain size distributions are significantly close; however, only the median value is significantly similar between the N1 and the P1 grain size distributions. The questionable accuracy of the photographic sampling procedure was further tested by subjecting the a and b axes measurements taken in the field, and the same axes measurements derived from a photograph, to a Wilcoxon Matched Pairs Signed

TABLE 5

The results of the Wilcoxon Matched Pairs Signed Ranks Test for the different field sampling procedures. Critical value at .05.

| Compared | to | Median | Mean | S.D. | Sk. | Ku. | Relationship of Mean values |
|---|---|---|---|---|---|---|---|
| G | Q | | | | X | X | G is Greater |
| G | Sc | | | | | X | G is Greater |
| Q | Sc | | | | X | | Q is Greater |
| N1 | N2 | | | X | X | X | N2 is Greater |
| N1 | N3 | X | X | X | X | X | |
| N1 | P1 | X | | | X | X | |
| N1 | P2 | | | | | | N1 is Greater |
| N2 | N3 | | | X | X | X | N2 is Greater |
| N2 | P1 | | | | X | X | N2 is Greater |
| N2 | P2 | | | | | X | N2 is Greater |
| N3 | P1 | X | X | | X | X | |
| N3 | P2 | | | | X | | N3 is Greater |
| P1 | P2 | | | X | | X | P1 is Greater |
| G | N1 | | | | | X | G is Greater |
| G | P1 | | | | | X | G is Greater |
| Sc | P1 | | | X | X | | P1 is Greater |
| Sc | N1 | | | | X | | N1 is Greater |
| Q | N1 | X | X | | X | X | |

Note: X indicates that differences between the pairs are not significant at the chosen probability level.

S.D. - Standard Deviation
Sk. - Skewness
Ku. - Kurtosis

Ranks Test. The results of the test are presented in Table 6. In all thirty test samples, a significant number of measurements derived from the photograph were smaller than those taken in the field. Most of this underestimation occurs in the smaller size stones and may not affect the assigned grain size class. However, in 18 of the 30 samples, the underestimation of axis length, by the photographic method, caused a significant difference in grain size distributions derived from field and photographic measurements.

In view of the results of these tests, the use of the photographic sampling procedure may be justifiable in circumstances where only an approximate median or mean value is desired.

The Wilcoxon Test has been applied to the five statistical parameters of the grain size distributions. Since this is the strongest test used for the comparative evaluation of sampling procedures, the more relevant individual combinations will be discussed with respect to the results of this test (Table 5).

The complete lack of significance in all paired statistical parameters indicates that the G grain size distribution is not representative of the Q grain size distribution. As Leopold (1970, abstract) points out, this is due to the "bias toward larger sizes". Leopold (1970) in fact used a N sample; however, the grid sampling method is employed in both N and G samples and it is merely the

TABLE 6

The results of the Wilcoxon Matched Pairs Signed Ranks Test of the Photographic Sampling Procedure - P1 and the Grid by Number Sampling Procedure - N1. Critical value at .05. Fifty paired axes measurements constitute each sample.

| Sample No. | Degree of Significance | Relationship of Paired Axes Measurements |
|---|---|---|
| 1 | | N is Greater than P |
| 2 | | N is Greater than P |
| 3 | X | |
| 4 | X | |
| 5 | | N is Greater than P |
| 6 | X | |
| 7 | | N is Greater than P |
| 8 | X | |
| 9 | | N is Greater than P |
| 10 | | N is Greater than P |
| 11 | X | |
| 12 | | N is Greater than P |
| 13 | | N is Greater than P |
| 14 | | N is Greater than P |
| 15 | X | |
| 16 | | N is Greater than P |
| 17 | X | |
| 18 | | N is greater than P |
| 19 | | N is Greater than P |
| 20 | | N is Greater than P |
| 21 | | N is Greater than P |
| 22 | X | |
| 23 | | N is Greater than P |
| 24 | | N is Greater than P |
| 25 | X | |
| 26 | | N is Greater than P |
| 27 | X | |
| 28 | | N is Greater than P |
| 29 | | N is Greater than P |
| 30 | X | |

Note: X indicates that differences between the pair of samples is not significant at the chosen probability level.

analysis which is different. Leopold converts N to G using the weighting factor $D^3$ and then accounts for the "bias" by weighting the value by $1/D^2$. The Wilcoxon test substantiates the theory - G is coarser than Q - by illustrating that the mean and median values of the G Sample are significantly larger than those of the Q Sample. Similarily, Table 5 reveals that the G Sample is significantly coarser than the Sc Sample. Likewise, the Q Sample is also coarser than the Sc Sample. Summarizing, G is coarser than Q which is coarser than Sc.

Table 5 also gives evidence that the G Sample is coarser than the N1 sample and that the N1 sample is coarser than the Sc sample. Of special interest is the results of the N1-Q combination. The Wilcoxon test reveals significantly similar mean and median values for this combination.

As in the lab study, those conversion factors suggested by the Kellerhals and Bray model (Table 1) were applied to the appropriate field data. The results of the K-S Test (Table 7) reveal that the converted grain size distributions are not significantly similar to an original distribution, (    example, the "N1 converted to Sc" grain size distribution is not significantly close to the "Sc" distribution). However, the results of the Wilcoxon Test (Table 8) show that; when median and mean values are considered, the G  Sample can be converted successfully to the Sc Sample, and similarily Q converts to Sc.

TABLE 7

The results of the Kolmogorov- Smirnov Two Sample Test of the converted field sampling procedures.

Critical value at .05.

| Converted from | to | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | %SS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G | Sc | | | | | | | | | | | | X | X | X | X | X | | | | | | | | | | | | | | | 16.7 |
| Q | Sc | X | X | X | X | X | | X | X | X | X | X | X | X | | | X | X | X | X | X | X | | X | X | X | | | X | X | X | 80.0 |
| G | Q | X | | | | X | | | | | X | | X | X | X | | X | X | | X | X | X | | | | | | | | | | 36.7 |
| Nl | G | | | X | | X | | | | | | X | | X | X | X | | | | | X | | X | | | | | | X | | | 30.0 |
| Nl | Q | | X | X | X | X | X | | | X | | X | | X | X | X | X | | | X | X | | | | X | X | X | | X | X | | 56.7 |

%SS - Percentage of test samples which are significantly similar at .05.
X - Indicates that differences between the pairs are not significant at the chosen probability level.

TABLE 8

The results of the Wilcoxon Matched Pairs Signed Ranks Test for the converted field sampling procedures. Critical value at .05.

| Converted from | to | Median | Mean | S. D. | Sk. | Ku. | Conversion Value |
|---|---|---|---|---|---|---|---|
| G | Sc | X | X | | X | X | $1/D^3$ |
| G | Sc | X | X | | X | | $1/D$ |
| G | Q | | | X | | X | $1/D^2$ |
| N1 | G | | | | X | X | $D^3$ |
| N1 | Q | | | X | | X | $D$ |

S.D. - Standard Deviation
Sk. - Skewness
Ku. - Kurtosis
X - Indicates that there is no significant difference between the pairs at the chosen probability level.

A successful conversion from N1 to Sc is not expected since the sampling methods examine different populations; i.e. surface versus volumetric.

Tables 7 and 8 indicate that the Kellerhals and Bray weighting factors for conversions N1 to Q, N1 to G* and N1 to Sc are not applicable. These transformations all involve conversions from the N1 Sample to some form of sieved sample (G, Q, and Sc). The reason for the failure of these conversions may be the result of a systematic difference in the measurement of axis made by sieves, and direct axis measurement. Both Van der Plas (1962) and Sahu (1964) discuss this difference. They point out that sieves sort not only by size but also by shape. Van der Plas also mentions that this tends to shift the grain size distribution curve toward finer sizes.

If a researcher collects a N1 Sample, the b axis of each stone is measured and, according to the size of this parameter, the stone is placed in a related sieve size group. As an example, 17 of 100 stones measured have a b axis of greater than 2 inches but less than 4 inches. However, when sieving, the stones retained in the so called 2" sieve do not have a minimum b axis value of 2". This is so since the 2" title refers to the size of a square hole and not the maximum hole size. In the case of a 2" sieve, the maximum

* Only in the coarsest sieve is this error significant. It is suggested that instead of a weighting factor equal to the geometric mean of the largest sieve size, a gometric mean value between the smallest and largest stone found in this sieve size class be applied.

hole size is $\sqrt{2^2 + 2^2} = 2.82$". Therefore, those elongated stones which have b axis smaller than 2.8" will pass through the sieve. It can be similarily shown that elongated stones with a b axis of 5.66", and 1.41" will pass through the so-termed 4" and 1" sieves respectively. Therefore, if the 100 stones are first measured and grouped into sieve size classes (N1 Sample) and then the same 100 stones are sieved into comparable size classes (C, Q, or Sc Sample), the population in each size group could and would probably by different. For example, suppose that 17 stones have a b axis which varies from 2" to 4", and that 17 stones are also retained in the 2" sieve. The b axis of these 17 stones ranges from 2.82" to 5.66". Likewise, the stones retained in the 1" sieve vary from 1.41" to 2.81". It would be safe to assume that some of the original 17 stones with b axis less than 2.82" but greater than 2", are actually included in the 1" sieve. Similarily, stones grouped by their b axis size into the 4" size size group will probably occur in the 2" sieve. Therefore, the frequency by weight and frequency by number must differ. Since the sieve will pass larger sizes than the stated sieve size group, the frequency by weight will be greater or coarser than frequency by number. This is supported by the results of the Wilcoxon Test (Table 5) which illustrates that the G sample is coarser than the N1 Sample.

Both these samples employ the same stones - the G Sample grouped them by sieving, the N1 Sample grouped according to b axis into the sieve size class.

Regarding the conversion of a N1 Sample to any sieved type of sample, the correct conversion factor must be used. The conversion factor for a 2" sieve is theoretically the geometric mean diameter in the group; i.e. $\sqrt{2 \times 4} = 2.82$. In reality, this is the minimum diameter and not the geometric mean. Whether this effect in itself has significant proportions is unknown.

It should be pointed out that in the Kellerhals and Bray model and in the lab study, this effect does not take place. Shape is of major importance in this effect. A spherical stone caught in a sieve may not weigh as much as an elongated one passing through the sieve. The researcher involved with coarse fluvial gravels must be aware of this problem, and if meaningful research is to be undertaken, true particle size groups must be employed.

However, Leopold (1970) suggests that the stones falling through sieves in which a spherical stone of the same intermediate axis would be retained do not significantly alter the grain size distribution (Leopold, 1970, Figure 3). It appears that this aspect of sieving requires a rigorous scientific study in order to clarify this problem.

## CHAPTER IV

Summary and Conclusions.

The study first examined a model described by Kellerhals and Bray (1971a). This model (Figure 1) suggests that different sampling procedures produce significantly different grain size distributions (Figure 2). It also hypothesizes that the grain size distribution of one sampling procedure may, by using a weighting factor, be converted to the grain size distribution resulting from any other sampling procedure.

The Kellerhals and Bray model (1971a) was then tested in a laboratory study. It was proven that many sampling procedures do, in fact, produce significantly different grain size distribution curves (Table 2). An interesting occurance in the laboratory samples, termed the "buried bead effect" (Figure 3), resulted in the failure of some conversion attempts (Table 3). However, when this effect was insignificant, the theoretical conversion factors (Table 1) were successful.

Of greater significance was the field study. Again several sampling procedures were subjected to comparative non-parametric statistical tests. The results of these tests (Table 4 and 5) illustrate that many sampling procedures produce significantly different grain size distribution curves (Appendix II). The one notable exception is the grid by number (b axis) and the grid by number (triaxial mean)

sampling procedures. However, when the reasearcher is interested in mean and median values only - the grid by number (triaxial mean) sample and the photographic grid (b axis) sample, the grid by number (b axis) sample and the photographic grid (b axis) sample, and the grid by number (b axis) sample and the quadrant by weight sample - all produce significantly similar results (Table 5).

When the suggested conversion values (Table 1) were applied and tested, it was found that none of the grain size distribution curves were significantly comparable (Table 7). However, if only mean and median values are considered, the grid by weight sample compares significantly to the volumetric sample - coarse fraction. Also, the quadrant by weight sample was significantly similar to the volumetric sample - coarse fraction. This is shown graphically in Appendix II. Conversions involving the grid by number (b axis) sample were unsuccessful due to a systematic error in methodology. When coarse fluvial gravels are examined, the fact that the stated sieve size is not the minimum size of the sieve hole may play a large role in exaggerating the coarseness of a sample. The researcher must acknowledge this bias and be especially careful when employing data derived from the grid by number method.

Other general conclusions may be listed as follows:

A. Generally, different sampling methods produce significantly different grain size distributions.

B. b axis measurements and triaxial mean measurements are, for practical purposes, equivalent.

C. A grid by number photographic sampling method produces a grain size distribution approximating that which results from a true grid by number sample.

D. Kellerhals and Bray (1971a) conversion values can equate the mean and median grain size values of certain sampling methods:

1. grid by weight to grid by number.
2. grid by weight to the coarse fraction of a volumetric sample.
3. area by weight to the coarse fraction of a volumetric sample.

E. A grid by number sample grain size distribution closely approximates the coarse fraction of a volumetric sample. This near equivalence is significantly close in 43% of test samples.

Note: If the fine portion of the volumetric grain size distribution is entirely removed, this value approaches 95%.

Of the many grain size sampling procedures available, each has definite advantages and disadvantages. It is the researcher's obligation to select the most appropriate sampling procedure for his study. In addition, he must be particularly aware of the shortcomings of the selected sampling procedure in order to produce meaningful and useful research.

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APPENDIX I

The Laboratory Data

| Sample No. | | Number in each Bead Size (in mm.) | | | |
|---|---|---|---|---|---|
| | | 25.4 | 15.8 | 6.0 | 3.0 |
| 1 | N | 0 | 6 | 28 | 66 |
| | A | 0 | 13 | 192 | 1130 |
| 2 | N | 6 | 6 | 42 | 56 |
| | A | 3 | 13 | 204 | 891 |
| 3 | N | 4 | 16 | 46 | 44 |
| | A | 2 | 22 | 207 | 674 |
| 4 | N | 8 | 12 | 26 | 54 |
| | A | 7 | 20 | 178 | 933 |
| 5 | N | 4 | 8 | 54 | 34 |
| | A | 3 | 16 | 243 | 599 |
| 6 | N | 2 | 18 | 52 | 28 |
| | A | 2 | 18 | 272 | 571 |
| 7 | N | 2 | 10 | 40 | 48 |
| | A | 2 | 14 | 191 | 952 |
| 8 | N | 4 | 12 | 46 | 38 |
| | A | 4 | 14 | 237 | 775 |
| 9 | N | 0 | 24 | 58 | 16 |
| | A | 1 | 24 | 288 | 445 |
| 10 | N | 2 | 8 | 46 | 44 |
| | A | 2 | 11 | 184 | 913 |

The Grid by Number (b axis) Samples

| Sample No. | The Number Retained in Each Size Class# 8.0 | 9.5 | 12.7 | 19.0 | 24.5 | 50.8 | 101.6 |
|---|---|---|---|---|---|---|---|
| 1 | 4 | 2 | 4 | 4 | 18 | 17 | 1 |
| 2 | 9 | 2 | 3 | 6 | 14 | 15 | 1 |
| 3 | 9 | 2 | 5 | 5 | 21 | 8 | 0 |
| 4 | 2 | 0 | 1 | 0 | 28 | 19 | 0 |
| 5 | 1 | 1 | 4 | 3 | 33 | 8 | 0 |
| 6 | 1 | 2 | 1 | 5 | 21 | 20 | 0 |
| 7 | 2 | 1 | 4 | 6 | 20 | 17 | 0 |
| 8 | 1 | 3 | 10 | 6 | 16 | 13 | 0 |
| 9 | 0 | 4 | 4 | 6 | 22 | 13 | 1 |
| 10 | 1 | 4 | 8 | 8 | 26 | 3 | 0 |
| 11 | 4 | 3 | 10 | 10 | 23 | 0 | 0 |
| 12 | 2 | 3 | 1 | 4 | 22 | 18 | 0 |
| 13 | 0 | 0 | 2 | 3 | 26 | 18 | 0 |
| 14 | 0 | 0 | 1 | 0 | 25 | 23 | 1 |
| 15 | 3 | 0 | 6 | 8 | 17 | 16 | 0 |
| 16 | 3 | 0 | 4 | 4 | 25 | 12 | 2 |
| 17 | 4 | 4 | 8 | 9 | 16 | 9 | 0 |
| 18 | 3 | 1 | 12 | 5 | 16 | 12 | 1 |
| 19 | 4 | 4 | 8 | 2 | 18 | 13 | 1 |
| 20 | 0 | 0 | 3 | 2 | 25 | 19 | 1 |
| 21 | 0 | 1 | 2 | 5 | 14 | 26 | 1 |
| 22 | 6 | 8 | 12 | 9 | 14 | 1 | 0 |
| 23 | 7 | 6 | 12 | 10 | 12 | 3 | 0 |
| 24 | 7 | 1 | 5 | 2 | 20 | 11 | 3 |
| 25 | 6 | 4 | 8 | 4 | 14 | 10 | 2 |
| 26 | 5 | 2 | 6 | 6 | 22 | 9 | 0 |
| 27 | 2 | 2 | 3 | 10 | 19 | 14 | 0 |
| 28 | 5 | 2 | 2 | 10 | 14 | 16 | 1 |
| 29 | 3 | 1 | 4 | 9 | 19 | 14 | 0 |
| 30 | 1 | 2 | 5 | 5 | 15 | 22 | 0 |

The Grid by Number (triaxial mean) Samples

| Sample No. | The Number Retained in Each Size Class # 8.0 | 9.5 | 12.7 | 19.0 | 25.4 | 50.8 | 101.6 |
|---|---|---|---|---|---|---|---|
| 1 | 4 | 1 | 4 | 7 | 19 | 15 | 0 |
| 2 | 8 | 4 | 3 | 5 | 13 | 17 | 0 |
| 3 | 6 | 6 | 5 | 5 | 19 | 9 | 0 |
| 4 | 2 | 0 | 1 | 3 | 26 | 18 | 0 |
| 5 | 0 | 1 | 5 | 5 | 26 | 13 | 0 |
| 6 | 1 | 2 | 1 | 7 | 20 | 18 | 1 |
| 7 | 1 | 2 | 2 | 7 | 21 | 17 | 0 |
| 8 | 0 | 6 | 8 | 7 | 14 | 14 | 1 |
| 9 | 0 | 3 | 6 | 5 | 27 | 9 | 0 |
| 10 | 1 | 2 | 9 | 12 | 22 | 4 | 0 |
| 11 | 1 | 5 | 7 | 12 | 23 | 2 | 0 |
| 12 | 1 | 4 | 2 | 3 | 21 | 19 | 0 |
| 13 | 0 | 0 | 0 | 4 | 27 | 18 | 0 |
| 14 | 0 | 0 | 0 | 1 | 27 | 22 | 0 |
| 15 | 2 | 1 | 4 | 12 | 16 | 15 | 0 |
| 16 | 3 | 0 | 3 | 5 | 24 | 14 | 1 |
| 17 | 4 | 5 | 5 | 11 | 17 | 8 | 0 |
| 18 | 2 | 2 | 8 | 7 | 18 | 12 | 0 |
| 19 | 3 | 5 | 6 | 6 | 18 | 11 | 1 |
| 20 | 0 | 0 | 1 | 4 | 27 | 18 | 0 |
| 21 | 0 | 1 | 2 | 7 | 15 | 23 | 2 |
| 22 | 4 | 8 | 17 | 11 | 10 | 0 | 0 |
| 23 | 7 | 7 | 10 | 13 | 11 | 2 | 0 |
| 24 | 7 | 0 | 7 | 3 | 18 | 10 | 5 |
| 25 | 4 | 6 | 8 | 5 | 14 | 9 | 3 |
| 26 | 5 | 2 | 6 | 6 | 25 | 6 | 0 |
| 27 | 2 | 2 | 3 | 12 | 20 | 11 | 0 |
| 28 | 5 | 3 | 2 | 10 | 17 | 13 | 0 |
| 29 | 3 | 0 | 6 | 7 | 22 | 12 | 0 |
| 30 | 0 | 2 | 8 | 5 | 13 | 22 | 0 |

The Photographic Sample - Grid by Number (b axis) Sampling

| Sample No. | The Number Retained in Each Size Class # 8.0 | 9.5 | 12.7 | 19.0 | 25.4 | 50.8 | 101.6 |
|---|---|---|---|---|---|---|---|
| 1 | 9 | 3 | 7 | 7 | 11 | 13 | 0 |
| 2 | 14 | 2 | 7 | 4 | 12 | 11 | 0 |
| 3 | 17 | 2 | 9 | 6 | 13 | 3 | 0 |
| 4 | 7 | 3 | 3 | 12 | 13 | 12 | 0 |
| 5 | 3 | 3 | 4 | 8 | 26 | 6 | 0 |
| 6 | 8 | 5 | 6 | 2 | 18 | 11 | 0 |
| 7 | 5 | 7 | 2 | 7 | 15 | 14 | 0 |
| 8 | 8 | 6 | 8 | 8 | 9 | 10 | 1 |
| 9 | 3 | 5 | 2 | 11 | 22 | 6 | 1 |
| 10 | 9 | 5 | 6 | 9 | 18 | 3 | 0 |
| 11 | 10 | 11 | 9 | 5 | 15 | 0 | 0 |
| 12 | 4 | 4 | 5 | 5 | 24 | 8 | 0 |
| 13 | 3 | 2 | 5 | 10 | 14 | 15 | 1 |
| 14 | 0 | 3 | 1 | 10 | 21 | 15 | 0 |
| 15 | 8 | 4 | 8 | 3 | 16 | 11 | 0 |
| 16 | 5 | 4 | 7 | 9 | 12 | 13 | 0 |
| 17 | 13 | 6 | 10 | 5 | 11 | 5 | 0 |
| 18 | 8 | 7 | 9 | 3 | 13 | 10 | 0 |
| 19 | 10 | 5 | 6 | 5 | 15 | 9 | 0 |
| 20 | 4 | 2 | 6 | 6 | 19 | 13 | 0 |
| 21 | 4 | 4 | 4 | 9 | 15 | 13 | 1 |
| 22 | 19 | 7 | 7 | 9 | 7 | 1 | 0 |
| 23 | 8 | 12 | 7 | 12 | 9 | 2 | 0 |
| 24 | 9 | 4 | 4 | 11 | 8 | 12 | 2 |
| 25 | 9 | 6 | 6 | 8 | 11 | 10 | 0 |
| 26 | 6 | 6 | 3 | 7 | 22 | 6 | 0 |
| 27 | 4 | 3 | 11 | 5 | 19 | 8 | 0 |
| 28 | 5 | 4 | 4 | 10 | 16 | 11 | 0 |
| 29 | 3 | 4 | 9 | 7 | 15 | 12 | 0 |
| 30 | 8 | 6 | 6 | 4 | 11 | 15 | 0 |

The Grid by Weight Samples

| Sample No. | The Amount in Grams* Retained in Each Sieve Class# 50.8 | 25.4 | 19.0 | 12.7 | 9.5 | 8.0 |
|---|---|---|---|---|---|---|
| 1 | 44906.4 | 20412.0 | 1814.4 | 453.6 | 453.6 | 453.6 |
| 2 | 53524.8 | 20865.6 | 1814.4 | 453.6 | 453.6 | 453.6 |
| 3 | 17236.8 | 10432.8 | 453.6 | 453.6 | 453.6 | 453.6 |
| 4 | 15876.0 | 32205.6 | 1360.8 | 453.6 | 453.6 | 453.6 |
| 5 | 64411.2 | 18597.6 | 1814.4 | 0.0 | 0.0 | 453.6 |
| 6 | 5896.8 | 25855.2 | 1360.8 | 907.2 | 453.6 | 0.0 |
| 7 | 42638.4 | 24494.4 | 4536.0 | 1360.8 | 0.0 | 453.6 |
| 8 | 37648.8 | 21772.8 | 2268.0 | 1814.4 | 453.6 | 453.6 |
| 9 | 32205.6 | 20412.0 | 453.6 | 453.6 | 0.0 | 453.6 |
| 10 | 3175.2 | 15876.0 | 4536.0 | 907.2 | 453.6 | 453.6 |
| 11 | 0.0 | 13608.0 | 1814.4 | 453.6 | 453.6 | 453.6 |
| 12 | 38556.0 | 19958.4 | 1360.8 | 0.0 | 226.8 | 226.8 |
| 13 | 102060.0 | 29937.6 | 1814.4 | 0.0 | 0.0 | 0.0 |
| 14 | 78472.8 | 29030.4 | 1360.8 | 0.0 | 0.0 | 0.0 |
| 15 | 87544.8 | 26308.8 | 3628.8 | 1360.8 | 453.6 | 453.6 |
| 16 | 63050.4 | 26762.4 | 2268.0 | 453.6 | 453.6 | 0.0 |
| 17 | 1814.4 | 19051.2 | 907.2 | 0.0 | 0.0 | 453.6 |
| 18 | 51256.8 | 16783.2 | 2721.6 | 0.0 | 0.0 | 2268.0 |
| 19 | 35834.4 | 17690.4 | 2268.0 | 907.2 | 453.6 | 453.6 |
| 20 | 61236.0 | 24494.4 | 1814.4 | 453.6 | 0.0 | 0.0 |
| 21 | 116121.6 | 25401.6 | 3628.8 | 1360.8 | 453.6 | 0.0 |
| 22 | 3175.2 | 2721.6 | 907.2 | 453.6 | 453.6 | 0.0 |
| 23 | 0.0 | 11340.0 | 1360.8 | 907.2 | 453.6 | 1814.4 |
| 24 | 128368.8 | 12700.8 | 1360.8 | 453.6 | 453.6 | 453.6 |
| 25 | 140616.0 | 10432.8 | 3628.8 | 2268.0 | 453.6 | 453.6 |
| 26 | 16329.6 | 21772.8 | 1360.8 | 907.2 | 453.6 | 453.6 |
| 27 | 30844.8 | 24494.4 | 2721.6 | 907.2 | 453.6 | 453.6 |
| 28 | 71215.2 | 18144.0 | 3628.8 | 453.6 | 453.6 | 453.6 |
| 29 | 36288.0 | 20412.0 | 2721.6 | 453.6 | 453.6 | 453.6 |
| 30 | 46267.2 | 24040.8 | 2721.6 | 1360.8 | 453.6 | 453.6 |

* The original weight was in pounds and converted to grams.

\# The size classes are given as the smallest value in millimeters retained in the sieve.

The Quadrant by Weight Samples

| Sample No. | The Amount in Grams* Retained in Each Sieve Class# 50.8 | 25.4 | 19.0 | 12.7 | 9.5 | 8.0 |
|---|---|---|---|---|---|---|
| 1 | 114760.8 | 168285.6 | 50803.2 | 24040.8 | 6350.4 | 22680.0 |
| 2 | 185522.4 | 115214.4 | 22680.0 | 10886.4 | 2721.6 | 16783.2 |
| 3 | 90720.4 | 122018.4 | 34927.2 | 22226.4 | 4536.0 | 29484.0 |
| 4 | 136987.2 | 206388.0 | 38102.4 | 19958.4 | 1360.8 | 8618.4 |
| 5 | 56246.4 | 278964.0 | 51710.4 | 20412.0 | 2268.0 | 6804.0 |
| 6 | 146512.8 | 146966.4 | 11340.0 | 4082.4 | 453.6 | 1360.8 |
| 7 | 90720.0 | 122925.6 | 33112.8 | 20412.0 | 1814.4 | 4989.6 |
| 8 | 84369.6 | 126554.4 | 36288.0 | 26308.8 | 3175.0 | 9072.0 |
| 9 | 103420.8 | 151048.8 | 39009.6 | 18597.6 | 907.2 | 3175.2 |
| 10 | 7711.2 | 134719.2 | 59875.2 | 63050.4 | 907.2 | 29937.6 |
| 11 | 4082.4 | 112946.4 | 45360.0 | 29937.6 | 4082.4 | 34927.2 |
| 12 | 62596.8 | 152409.6 | 30391.2 | 17690.4 | 2268.0 | 27669.6 |
| 13 | 301644.0 | 300736.8 | 69400.8 | 1814.4 | 0.0 | 4082.4 |
| 14 | 226800.0 | 379663.2 | 110678.4 | 36741.6 | 453.6 | 5443.2 |
| 15 | 123379.2 | 107049.6 | 30391.2 | 14515.2 | 1814.4 | 3175.2 |
| 16 | 155584.8 | 141976.8 | 36741.6 | 22226.4 | 1814.4 | 15422.4 |
| 17 | 12247.2 | 69400.8 | 28576.8 | 26308.8 | 3628.8 | 24494.4 |
| 18 | 89359.2 | 101606.4 | 32205.6 | 24494.4 | 5896.8 | 18144.0 |
| 19 | 99792.0 | 100699.2 | 32205.6 | 24948.0 | 6350.4 | 19504.8 |
| 20 | 300283.2 | 358797.6 | 57153.6 | 15422.4 | 453.6 | 907.2 |
| 21 | 348818.4 | 276242.4 | 43092.0 | 22680.0 | 2268.0 | 4989.6 |
| 22 | 6804.0 | 43092.0 | 40824.0 | 65318.4 | 6350.4 | 46267.2 |
| 23 | 14061.6 | 67586.4 | 46267.2 | 50349.6 | 5443.2 | 49442.4 |
| 24 | 296200.8 | 102513.6 | 24040.8 | 8618.4 | 2721.6 | 4536.0 |
| 25 | 281232.0 | 105235.2 | 32205.6 | 15422.4 | 3628.8 | 6350.4 |
| 26 | 53071.2 | 141523.2 | 24494.4 | 10886.4 | 907.2 | 907.2 |
| 27 | 88905.6 | 148327.2 | 33112.8 | 13608.0 | 2721.6 | 1360.8 |
| 28 | 186429.6 | 131544.0 | 26762.4 | 17236.8 | 2268.0 | 4536.0 |
| 29 | 105235.2 | 147420.0 | 24948.0 | 14515.2 | 2721.6 | 2268.0 |
| 30 | 101152.8 | 130636.8 | 27216.0 | 12700.8 | 4989.6 | 1814.4 |

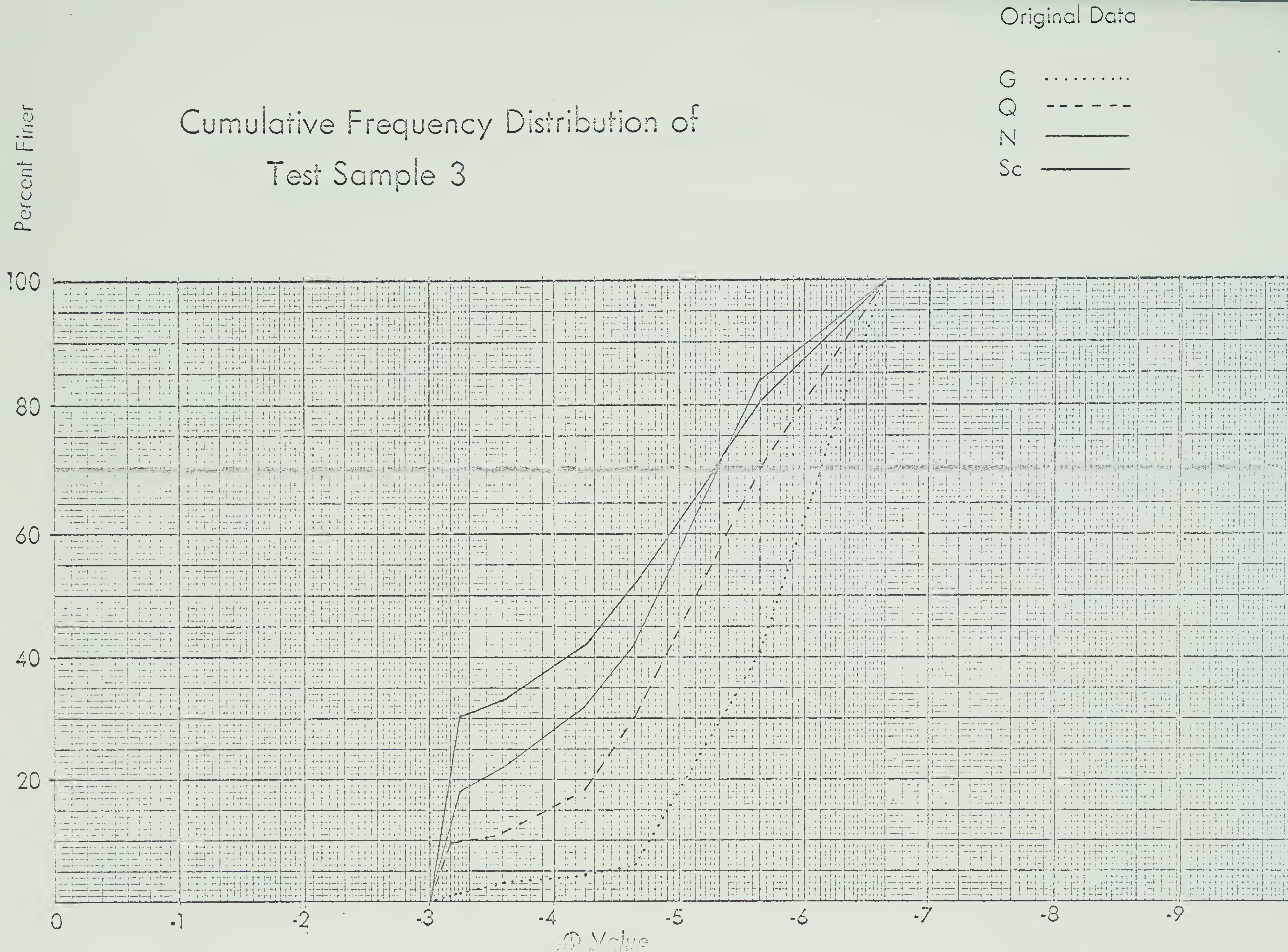
Note: The weights include the Grid Sample weight.

Coarse Fraction of the Volumetric Samples

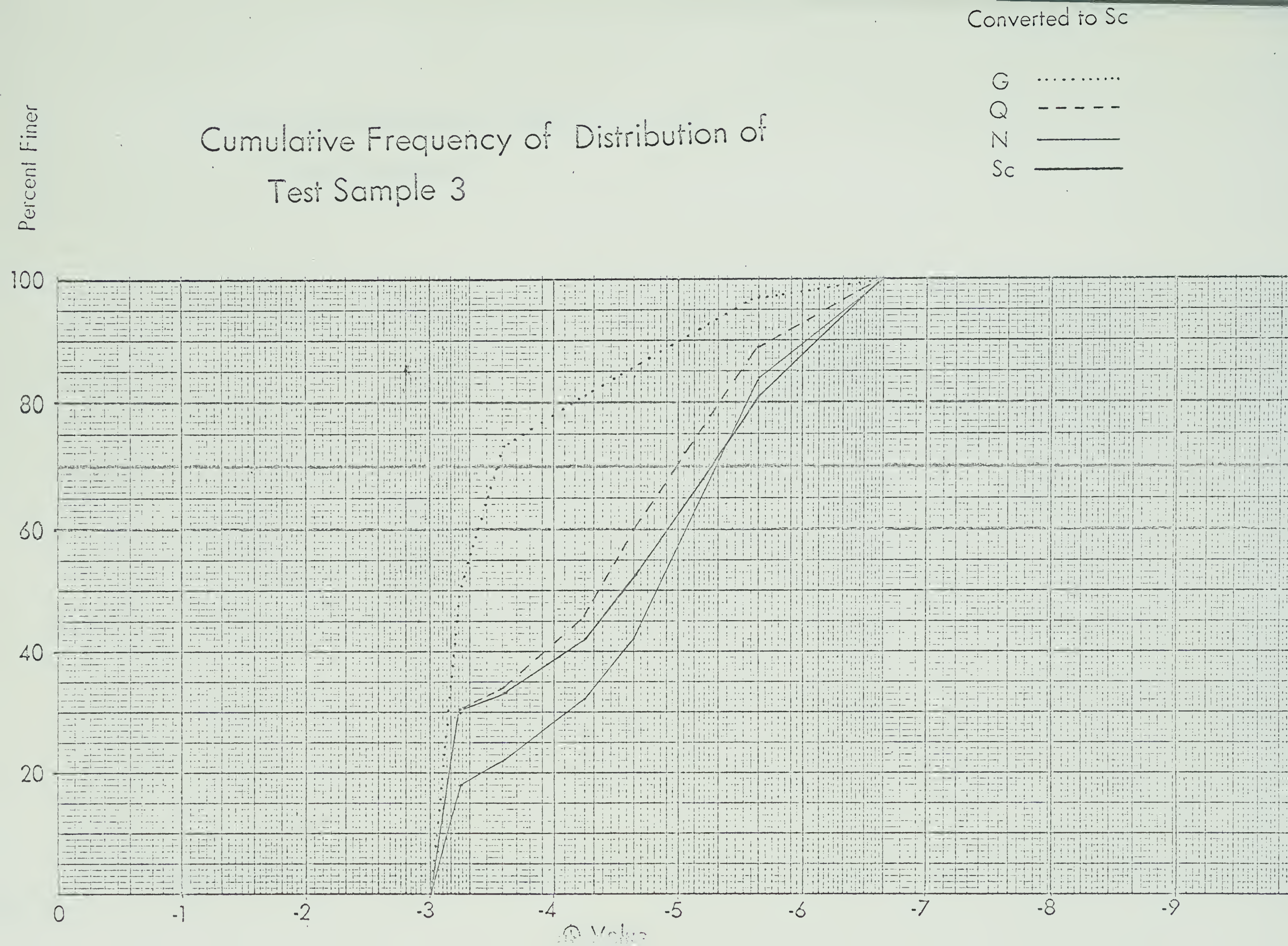
| Sample No. | The Amount in Grams* Retained in Each Sieve Class # 50.8 | 25.4 | 19.0 | 12.7 | 9.5 | 8.0 |
|---|---|---|---|---|---|---|
| 1 | 15876.0 | 71668.8 | 22226.4 | 27669.6 | 9525.6 | 146966.4 |
| 2 | 17236.8 | 49442.4 | 24040.8 | 32205.6 | 17690.4 | 135626.4 |
| 3 | 24494.4 | 43092.0 | 27669.6 | 31298.4 | 7711.2 | 154224.0 |
| 4 | 39009.6 | 67586.4 | 22680.0 | 27216.0 | 6350.4 | 81648.0 |
| 5 | 15876.0 | 70761.6 | 45813.6 | 36741.6 | 6804.0 | 83462.4 |
| 6 | 14515.2 | 64411.2 | 16329.6 | 22680.0 | 6350.4 | 121111.2 |
| 7 | 43545.6 | 73483.2 | 30391.2 | 43092.0 | 7711.2 | 143337.6 |
| 8 | 20865.6 | 70308.0 | 24040.8 | 29030.4 | 8618.4 | 133812.0 |
| 9 | 27216.0 | 73029.6 | 33566.4 | 58060.8 | 13154.4 | 125193.6 |
| 10 | 46720.8 | 73936.8 | 54885.6 | 64864.8 | 14061.6 | 141523.2 |
| 11 | 7257.6 | 87998.4 | 52617.6 | 81648.0 | 11793.6 | 223171.2 |
| 12 | 102513.6 | 147873.6 | 67132.8 | 89812.8 | 28123.2 | 424569.6 |
| 13 | 203212.8 | 189604.8 | 38102.4 | 12700.8 | 0.0 | 75297.6 |
| 14 | 187790.4 | 185976.0 | 39009.6 | 17236.8 | 907.2 | 75297.6 |
| 15 | 36288.0 | 189604.8 | 108864.0 | 128822.4 | 29030.4 | 492609.6 |
| 16 | 48988.8 | 121564.8 | 72576.0 | 94348.8 | 14515.2 | 120657.6 |
| 17 | 19958.4 | 122472.0 | 77112.0 | 68040.0 | 16329.6 | 276242.4 |
| 18 | 23133.6 | 90266.4 | 48081.6 | 72576.0 | 16783.2 | 223624.8 |
| 19 | 42184.8 | 72122.4 | 47174.4 | 64864.8 | 23587.2 | 238593.6 |
| 20 | 175089.6 | 205934.4 | 81648.0 | 34473.6 | 4536.0 | 5443.2 |
| 21 | 252201.6 | 117028.8 | 39916.8 | 39916.8 | 10886.4 | 85276.8 |
| 22 | 32659.2 | 125193.6 | 82555.2 | 94348.8 | 23587.2 | 141523.2 |
| 23 | 0.0 | 70761.6 | 46267.2 | 82555.2 | 17236.8 | 121564.8 |
| 24 | 48081.6 | 59875.2 | 40370.4 | 52164.0 | 19504.8 | 150595.2 |
| 25 | 43545.6 | 64411.2 | 31752.0 | 73483.2 | 17236.8 | 217728.0 |
| 26 | 13154.4 | 58060.8 | 25876.8 | 29484.0 | 6804.0 | 105688.8 |
| 27 | 8618.4 | 72576.0 | 31298.4 | 43999.2 | 9525.6 | 146059.2 |
| 28 | 31398.4 | 51256.8 | 21772.8 | 34927.2 | 5396.8 | 122925.6 |
| 29 | 19051.2 | 61236.0 | 21772.8 | 34020.0 | 12700.8 | 118843.2 |
| 30 | 13608.0 | 49442.4 | 22226.4 | 35834.4 | 7711.2 | 114307.2 |

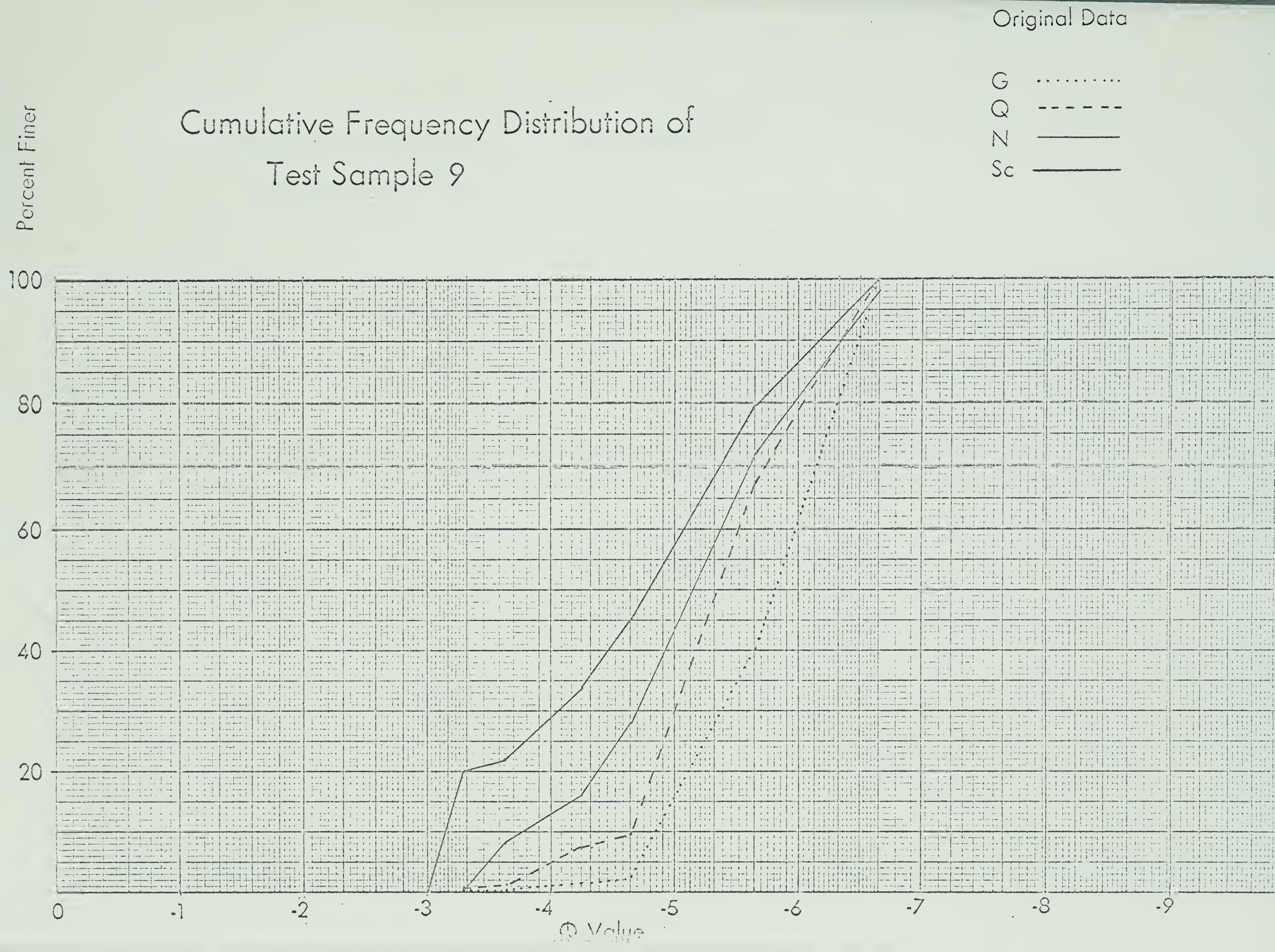
Note: The weights do not include the Quadrant Sample weight.

APPENDIX II

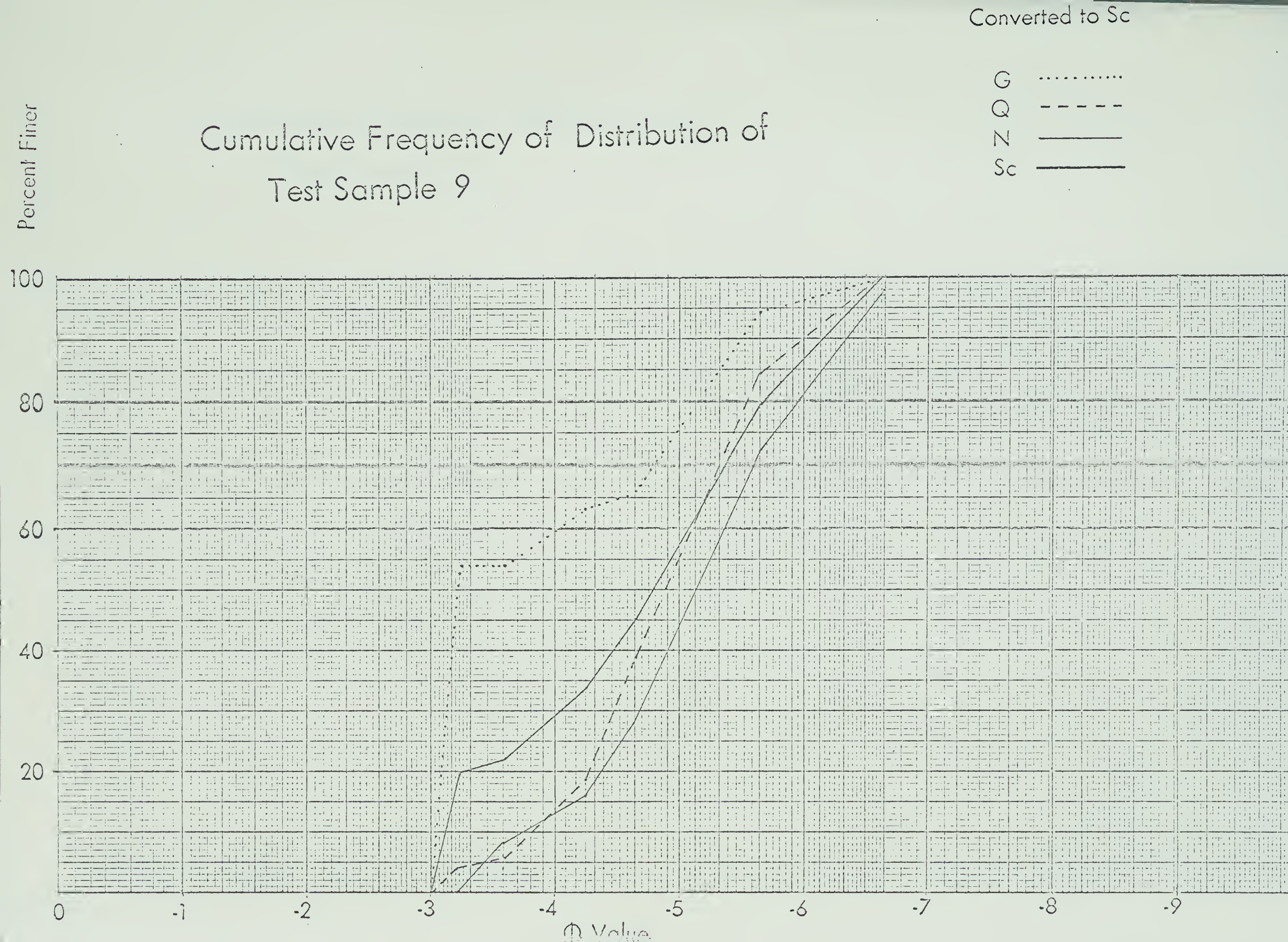


Cumulative Frequency Distribution of
Test Sample 3
Original Data
G
Q
N
Sc
Percent Finer
100
80
60
40
20
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
Φ Value


Cumulative Frequency of Distribution of
Test Sample 3
Converted to Sc
G
Q
N
Sc
Percent Finer
100
80
60
40
20
0
-1
-2
-3
-4
-5
-6
-7
-8
-9

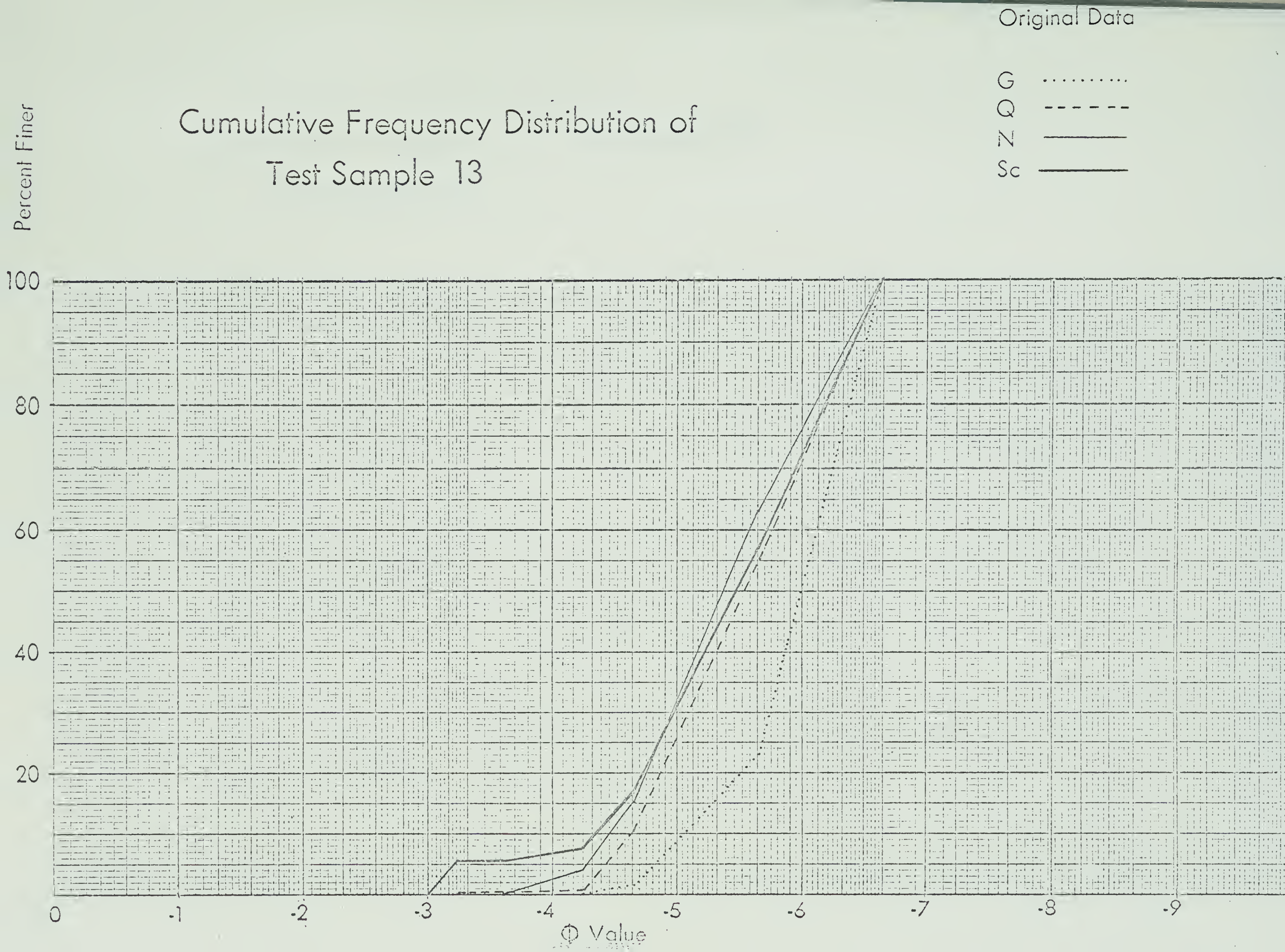


Cumulative Frequency Distribution of
Test Sample 9
Original Data
G
Q
N
Sc
Percent Finer
100
80
60
40
20
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
Φ Value

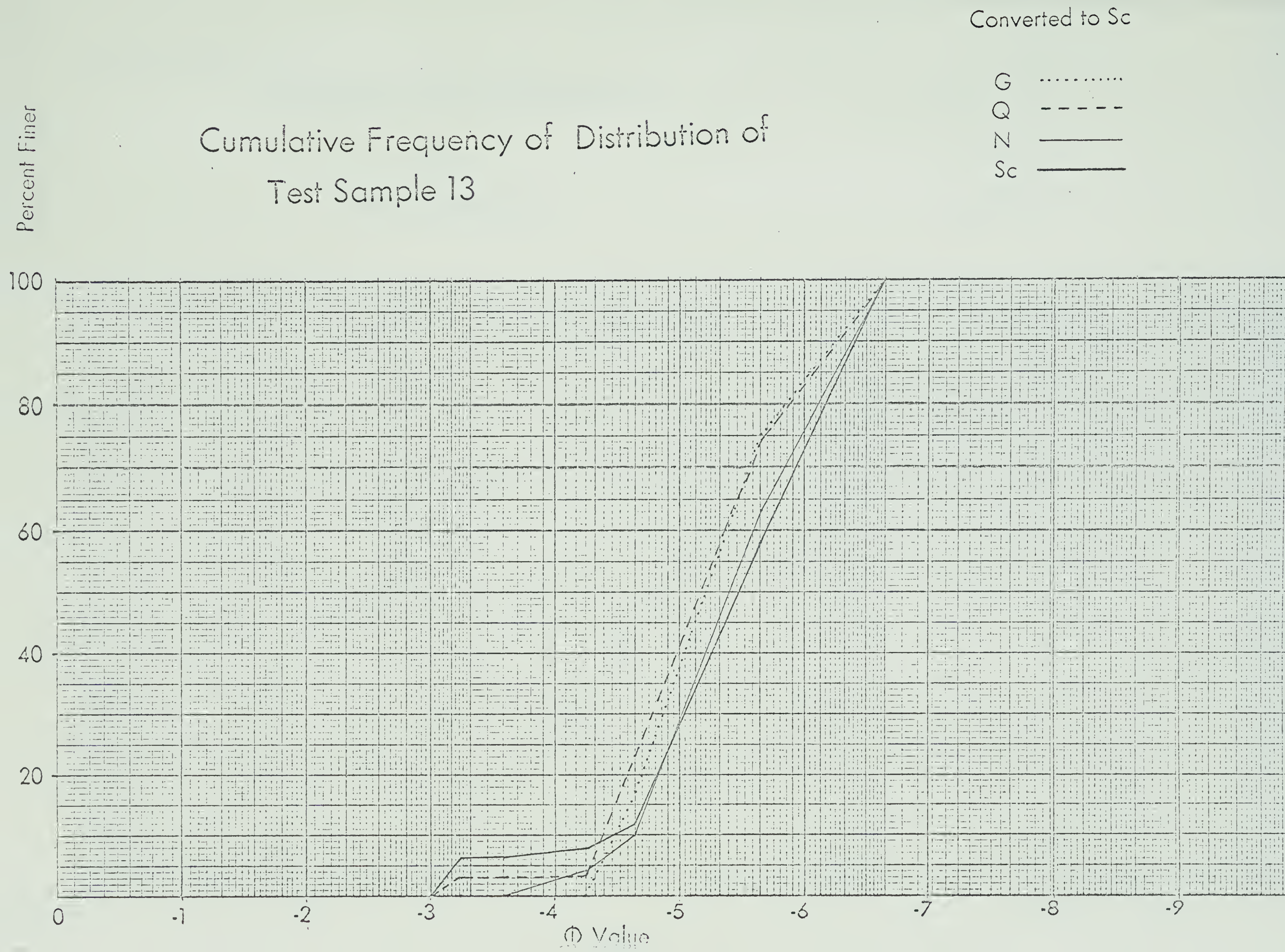


Cumulative Frequency of Distribution of
Test Sample 9
Converted to Sc
G
Q
N
Sc
Percent Finer
100
80
60
40
20
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
Φ Value

Cumulative Frequency Distribution of
Test Sample 13



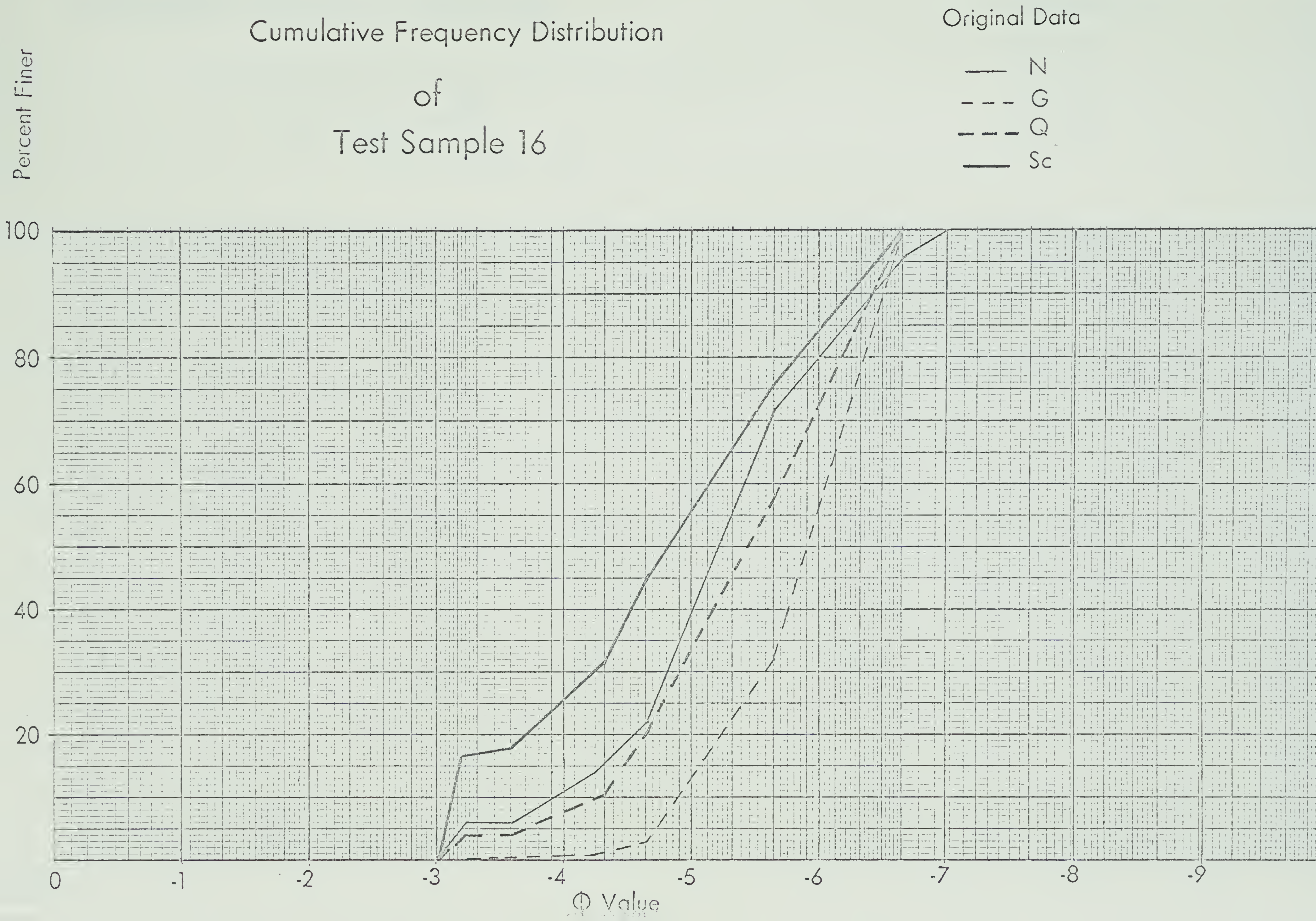
Cumulative Frequency of Distribution of Test Sample 13



# Cumulative Frequency Distribution

of

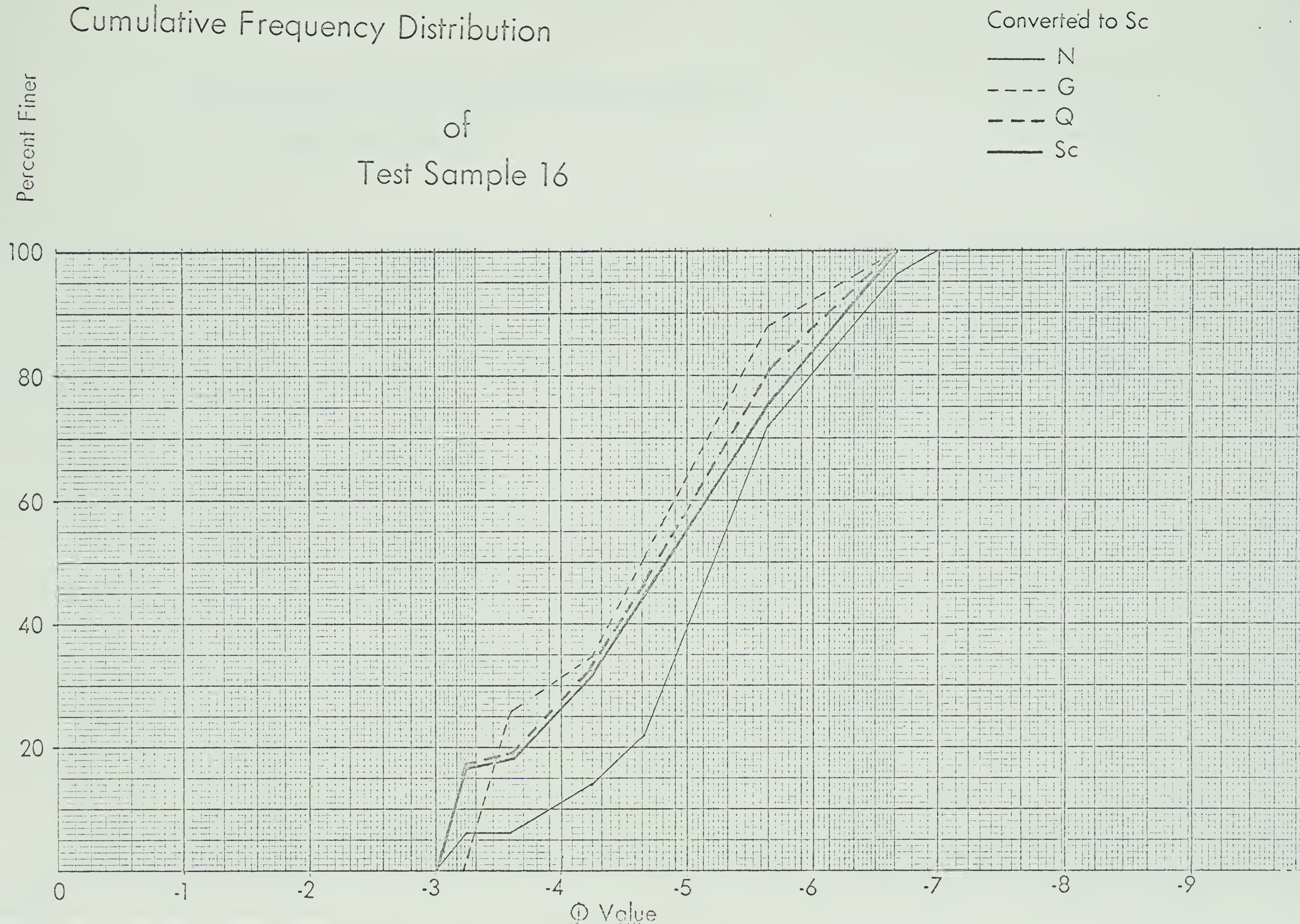
Test Sample 16



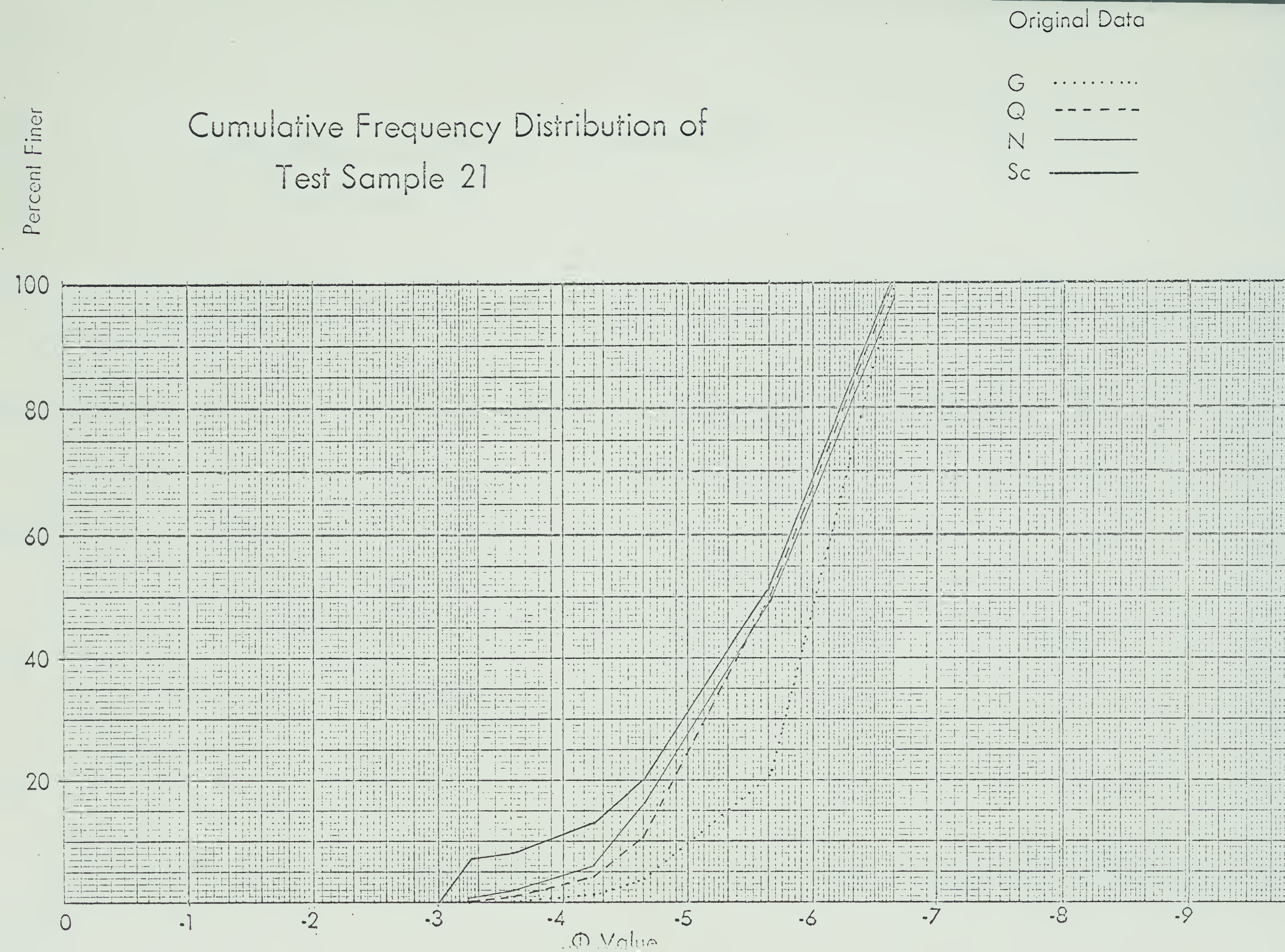
Cumulative Frequency Distribution

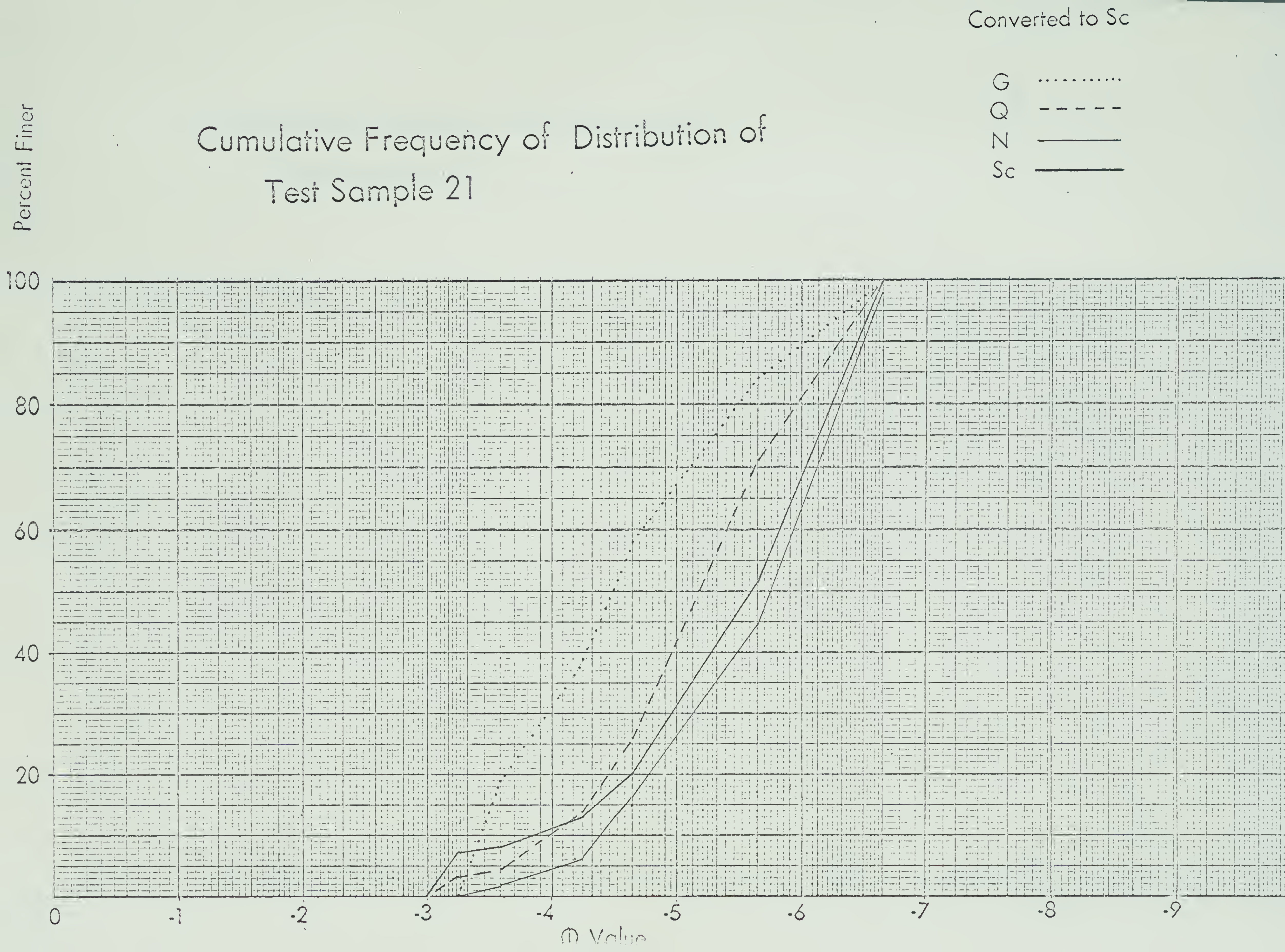
of

Test Sample 16

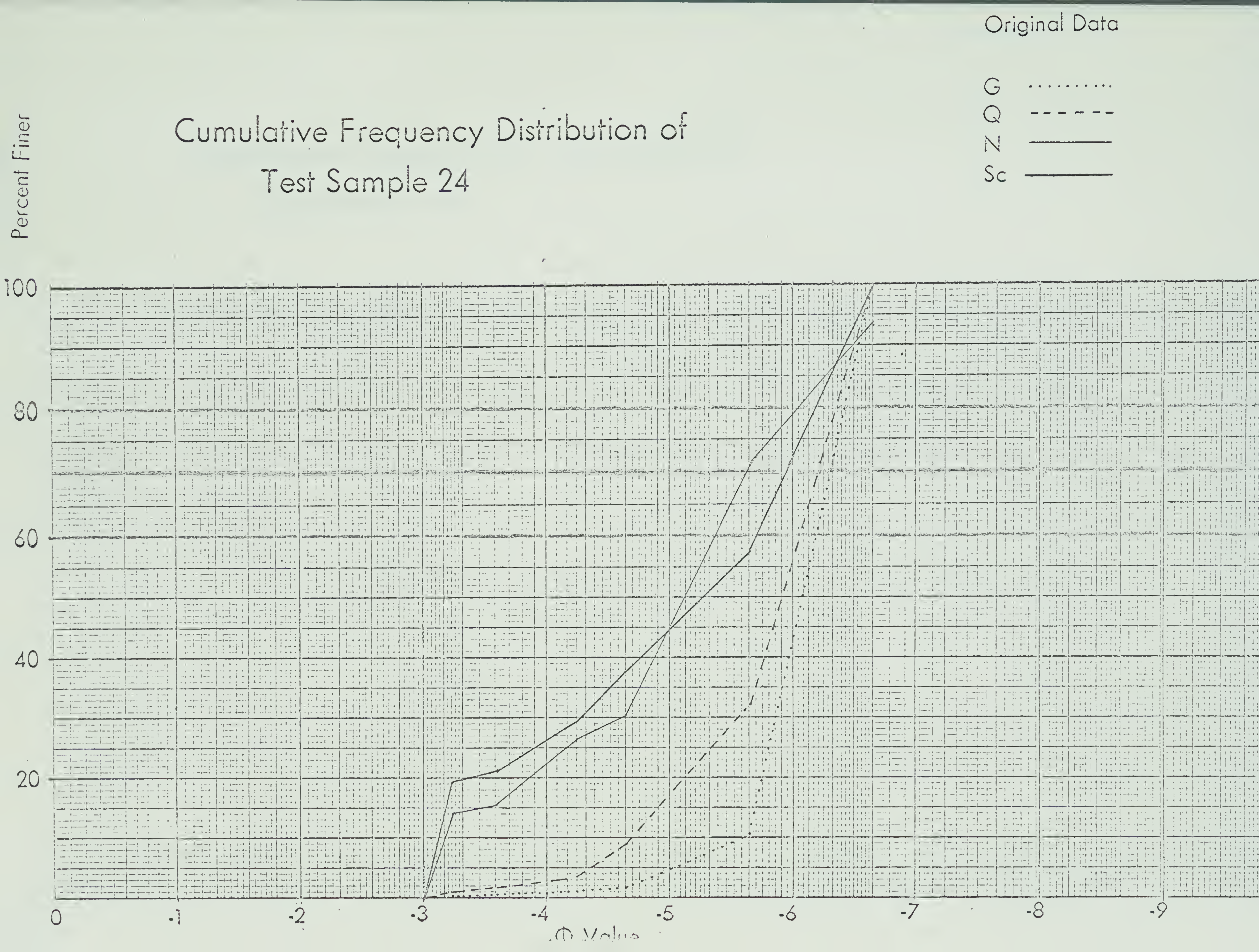


# Cumulative Frequency Distribution of Test Sample 21

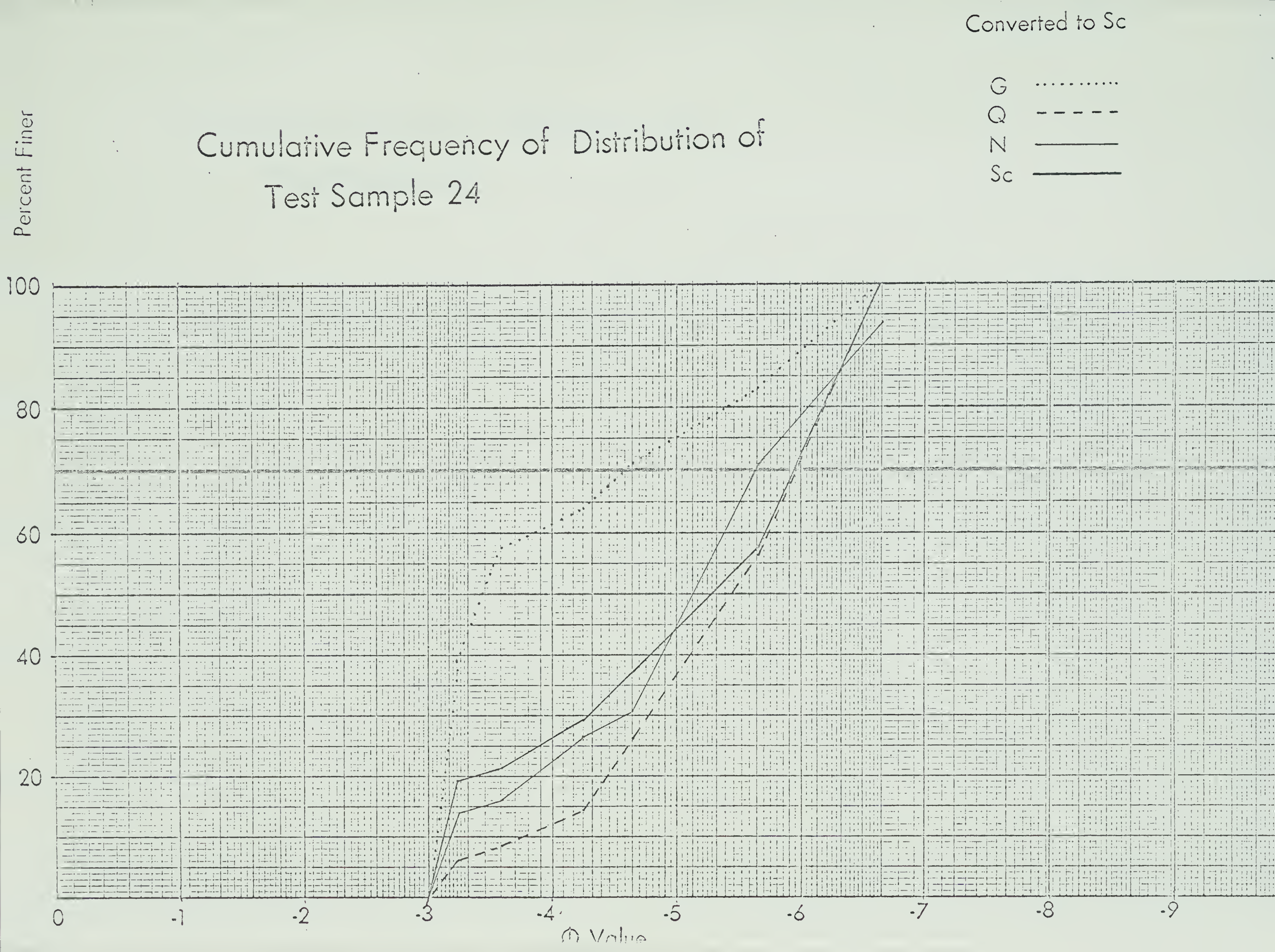




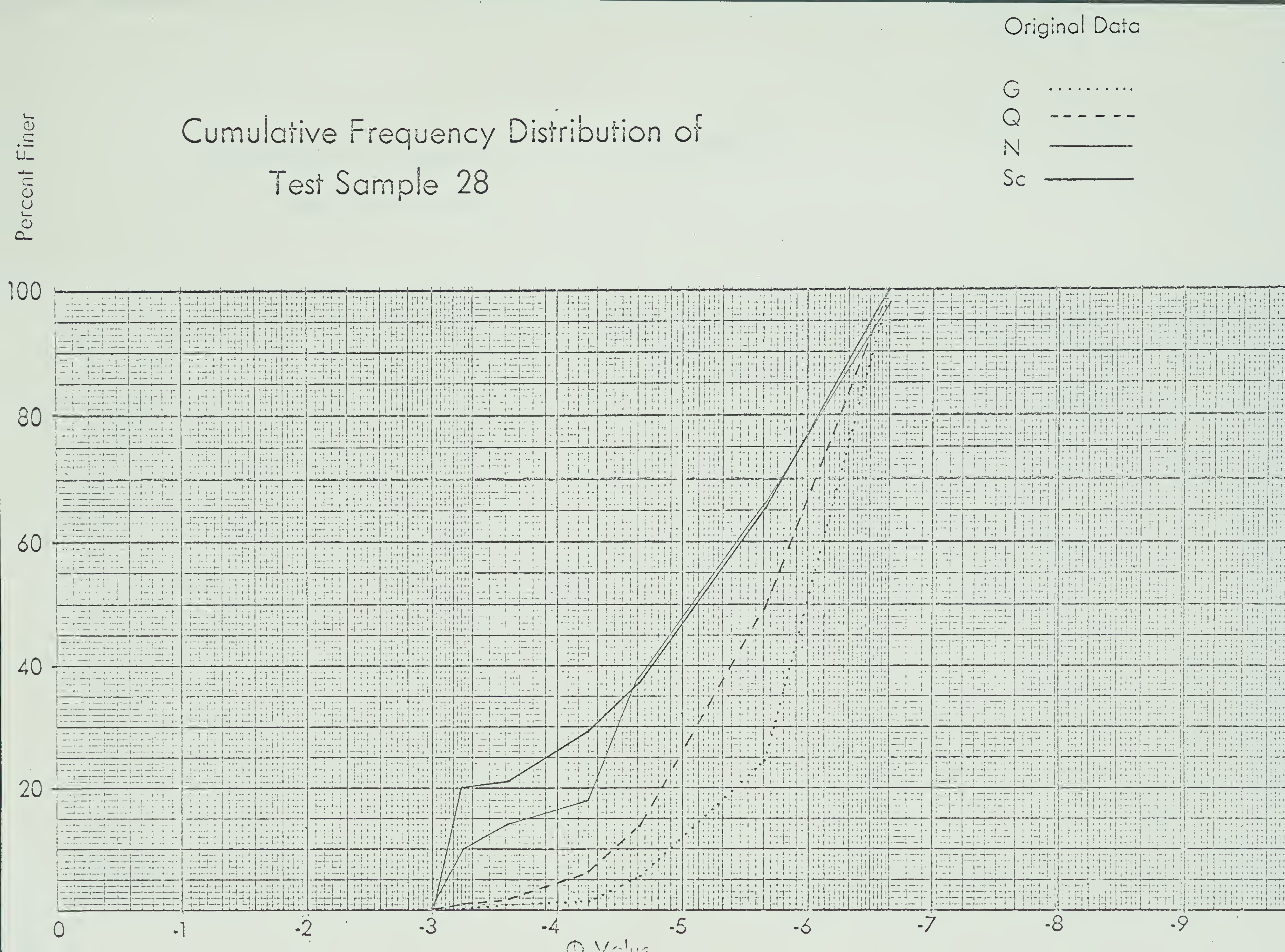
Cumulative Frequency of Distribution of
Test Sample 21
Converted to Sc
G
Q
N
Sc
Percent Finer
100
80
60
40
20
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
Φ Value


Cumulative Frequency Distribution of
Test Sample 24
Original Data
G
Q
N
Sc
Percent Finer
100
80
60
40
20
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
Φ Value

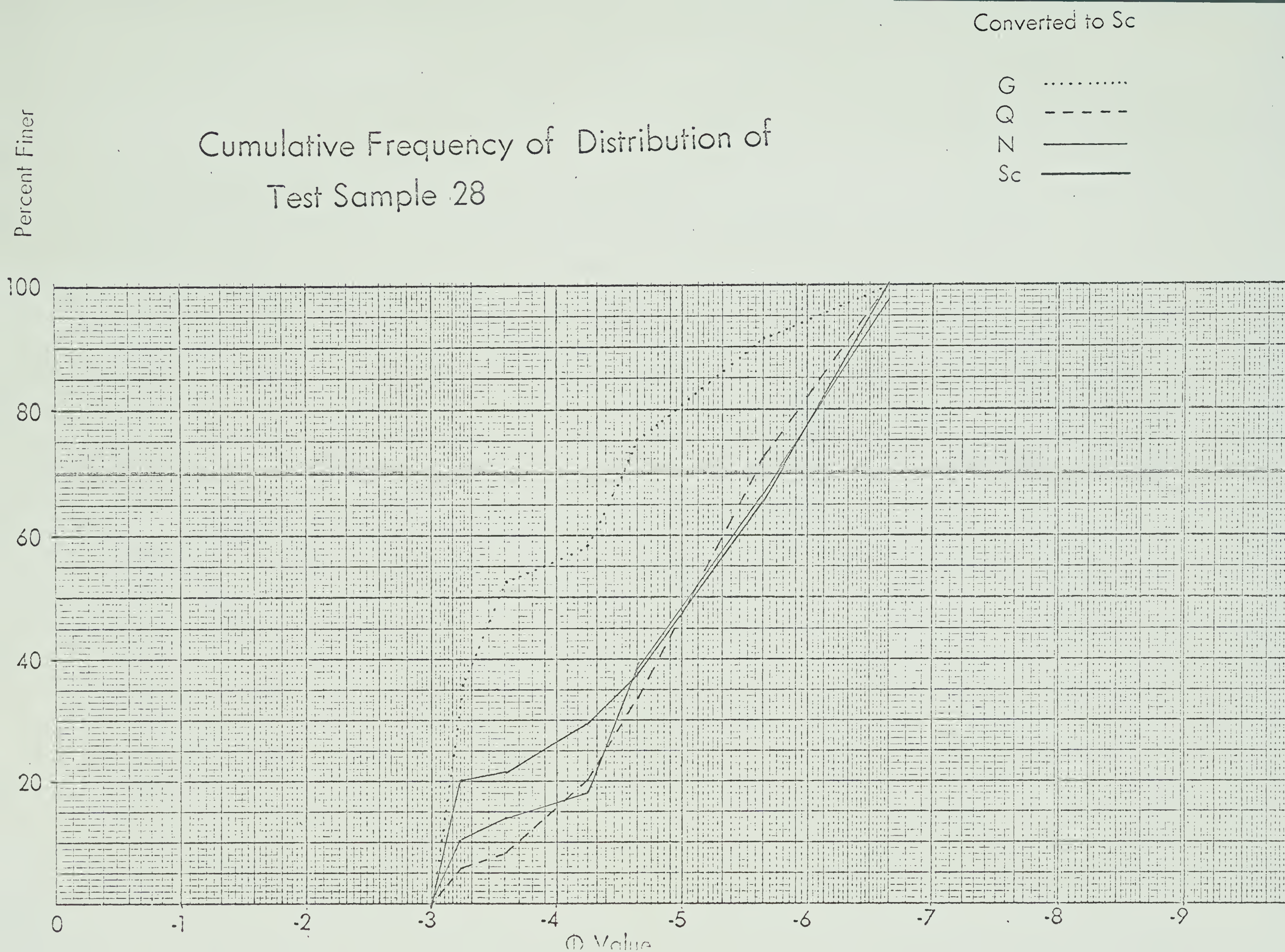
## Cumulative Frequency of Distribution of Test Sample 24



# Cumulative Frequency Distribution of Test Sample 28



Cumulative Frequency of Distribution of Test Sample 28



# APPENDIX III

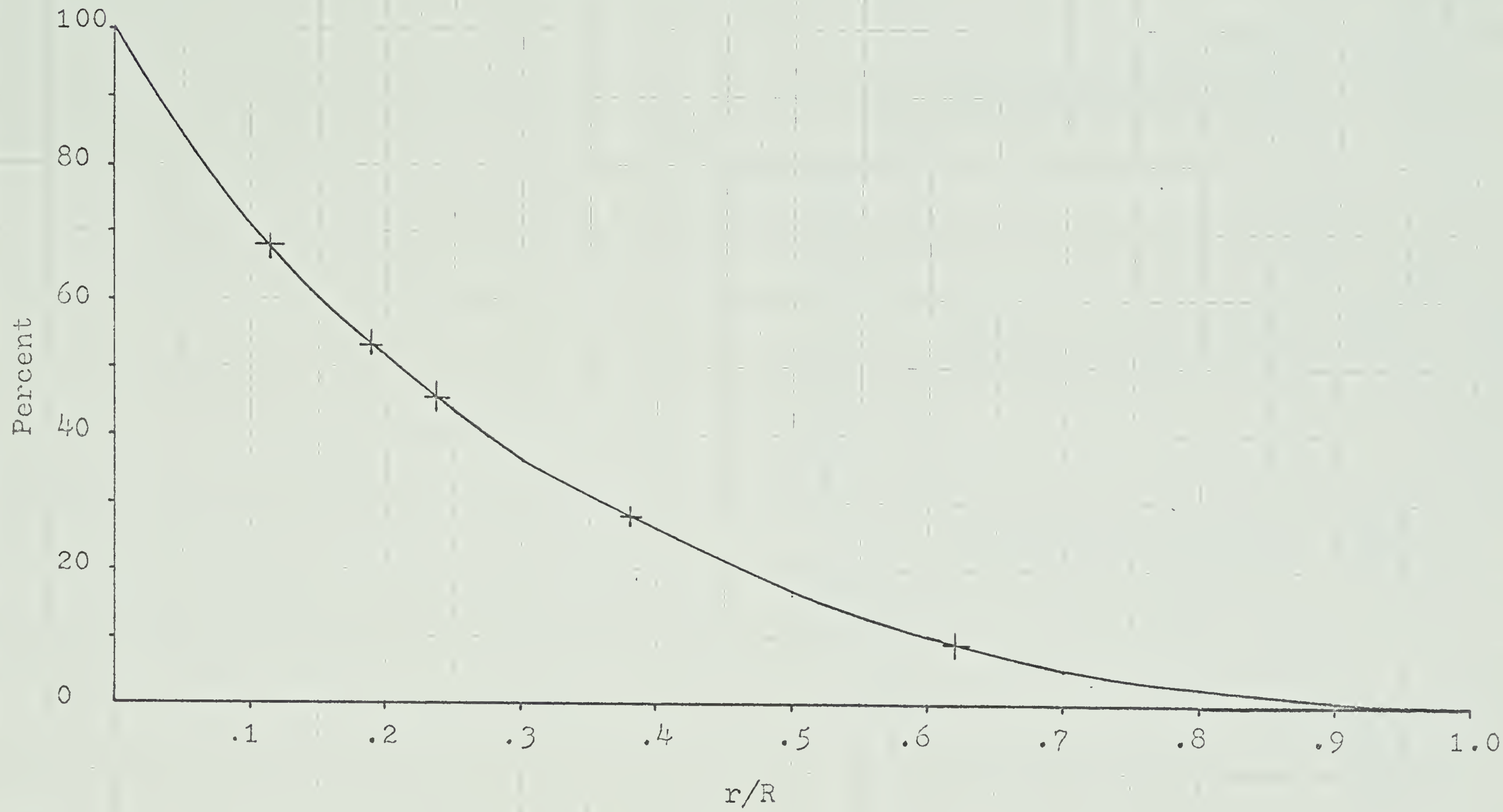
Appendix IIIa

| r/R | Amount of Burial $\dfrac{R^2 - (2\sqrt{rR} - r)^2}{R^2} \times 100$ |
|---|---|
| 0.000 | 100.0 |
| .050 | 84.2 |
| .100 | 71.7 |
| .115 | 68.0* |
| .150 | 60.1 |
| .189 | 54.0* |
| .200 | 51.8 |
| .236 | 47.0* |
| .250 | 43.8 |
| .300 | 36.6 |
| .379 | 28.0* |
| .400 | 26.4 |
| .500 | 16.5 |
| .600 | 10.1 |
| .622 | 9.0* |
| .700 | 5.1 |
| .800 | 2.4 |
| .900 | 0.4 |
| 1.000 | 0.0 |

*Derived from Appendix IIIb.

## APPENDIX IIIb

AMOUNT OF BURYING FACTORS FOR $r/R$



Appendix IIIc

| Dia. of #1 | Dia. of #2 | Ratio r/R | Amount of Burial * % |
|---|---|---|---|
| 25.4 | 15.8 | .622 | 9 |
| 25.4 | 6.0 | .236 | 46 |
| 25.4 | 3.0 | .115 | 68 |
| 15.8 | 6.0 | .379 | 28 |
| 15.8 | 3.0 | .189 | 54 |
| 6.0 | 3.0 | .500 | 17 |

*Derived from Appendix IIIb.